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DISSERTATION ABSTRACT

THE RELATIVE EFFECTIVENESS OF STRUCTURES AS PROTECTION
FROM GAMMA RADIATION FROM CLOUD AND FALLOUT SOURCES
AS A FUNCTION OF SOURCE ENERGY

BY
James Paul Fingerlos, B.S., M.E.
Major, United States Air Force
1984
178 pages
For the degree Doctor of Philosophy
The Ohio State University

It is necessary to know how much protection structures provide to determine what doses the public might receive if they try to evacuate or seek shelter from a release of radioactive material. This information is well known for only a few gamma ray spectra, such as that from weapon fallout. This research transfers the knowledge gained from weapon fallout work to protection factors for any gamma spectrum.

Point kernel models were developed for both fallout and cloud sources. That development included a method of accurately combining buildup factors in multi-region problems over wide ranges of energy and photon mean free path, and a method for calculating the effect of ground roughness on the attenuation factor for fallout sources. The results were reported for six spectra as well as discrete energies from 15 KeV to 15 MeV. The structures used as examples include small wood frame and large brick houses.

The results show that the protection provided by houses for the PWR-2 event is approximately equal to that for the 1-hr weapon fallout. However there are significant differences for other spectra, such as that from Three Mile Island. The effects of varying building size are reported as well as the relative importance of both cloud and fallout sources that infiltrate structures.

The bibliography includes *Structure Shielding from Cloud and Fallout Gamma Ray Sources for Assessing the Consequences of Reactor Accidents*, by Burson and Profio; *Structure Shielding Against Fallout Gamma Rays From Nuclear Detonations*, by Spencer, Chilton and Eisenhauer, and 79 other sources.

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AUTHOR: FINGERLOSS, JAMES PAUL

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THE RELATIVE EF. .CTIVENESS OF STRUCTURES AS PROTECTION FROM GAMMA RADIATION FROM CLOUD AND FALLOUT SOURCES AS A FUNCTION OF SOURCE ENERGY

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

By

James Paul Fingerlos, B.S., M.E.

* * * * *

The Ohio State University

1984

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Dedicated to

Sarah,

Todd, Joshua,

and Jennifer.

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LIST OF SYMBOLS

Symbol	Definition
B(E,mfp,Z)	buildup factor as a function of energy, mfp and material Z number (page 21)
B_{COMB}	Combined buildup factor (page 64)
B_{wall}	Buildup factor of wall (page 64)
B_{air}	Buildup factor of air (page 64)
BUF or B	Buildup Factor (page 12)
d	width of flat surface adjacent to trough (Figure 7, page 44)
DRF	Dose Reduction Factor (page 7)
D_R	Dose at R (page 21)
D_O	Reference Dose at R (page 21)
G(r)	Point kernel (page 12)
mfp or mfps	mean free path(s)
mfp_1	number of mean free paths between points "0" and "1" (Figure 3, page 20)
mfp_2	number of mean free paths between points "1" and "2" (Figure 3, page 20)
mfp_T	number of mean free paths between points "0" and "2" (Figure 3, page 20)
R or r	radial distance (distance units) (page 12)

LIST OF SYMBOLS (continued)

Symbol	Definition
S_O	Source Strength (page 12)
t	mass thickness of walls or roof in gr/cm2
t_{AVE}	Average thickness of ground photons must pass through (page 53)
t_{MAX}	Maximum thickness of ground photons must pass through (Figure 7, page 44)
t_{REP}	Representative thickness of ground photons must pass through (page 53)
w	trough width (Figure 7, page 44)
Z_1	A region composed of material of atomic number Z_1 (page 22)
$Z_{1,2}$	A region composed of a layer of material Z_1 and a layer of material Z_2 (page 22)
α, k, A, B, a, b	constants
β	grazing angle (Figure 7, page 44)
$\beta_{\frac{1}{2}}$	Half-Shadow angle (page 45
η	DRF (page 45)
μ	linear attenuation factor (1/cm) (page 12)
π	3.141592654
ϕ	Flux (photons/cm^2/sec) (page 12)
ψ	trough angle (Figure 7, page 44)

CHAPTER I

INTRODUCTION

1.1 Origin of the Problem

In the event of an unplanned release of radioactive material, it is necessary to know the doses the public could receive in order to make decisions that minimize risk to that public. The research reported here is as outgrowth of preliminary work done to determine what doses the public might receive if they try to evacuate or seek shelter.

Figure 1 is the flow chart of a conceptual program designed to determine which alternative provides the lowest dose to individuals. The alternatives are: taking no action; seeking shelter in homes; seeking shelter in other buildings, such as factories or schools; or evacuating. The input includes weather data and the chemical and isotopic nature of the release. A dispersion and deposition model determines the real time and projected concentrations in the radioactive cloud and fallout. The infiltration models determine how much material gets inside the structures. The structure shielding (and vehicle shielding) models determine how much the unprotected dose is reduced by available structures. The dose models compute the doses from the

fallout and the cloud sources. An evacuation model estimates how fast and in what direction the population is expected to exit in the event evacuation is ordered. A time use model estimates how much time an unwarned population would spend indoors, outdoors, or in vehicles. The result of the program is three dose estimates for the populations in each sector around the accident and at different ranges from the accident. These doses are: a sheltered dose, a "do nothing dose" for the option of not warning the population, and a dose received while evacuating. With this information, an official can make informed decisions as to what the public should be told. Ideally this program would be contained in mini-computers available near the release site and would provide results in seconds or at most a few minutes. The research reported here was done to provide data for the structure shielding subroutines of such a program. However, the bibliography included in this paper is a survey of literature applicable to the total problem concerning which action alternative provides the lowest dose.

1.2 Research Objective

The objective of this research is to develop a model for the protection provided by structures, such as homes, against releases of airborne radioactive material as a function of the gamma energy spectrum of the released material. Doses received through the food chain or inhalation are not considered.

It is not necessary to do a detailed analysis of each structure. The results of detailed studies, both mathematical and empirical have been reported for a few spectra and building types. Therefore the purpose of this research is not to calculate protection factors, but rather to show how they vary with energy.

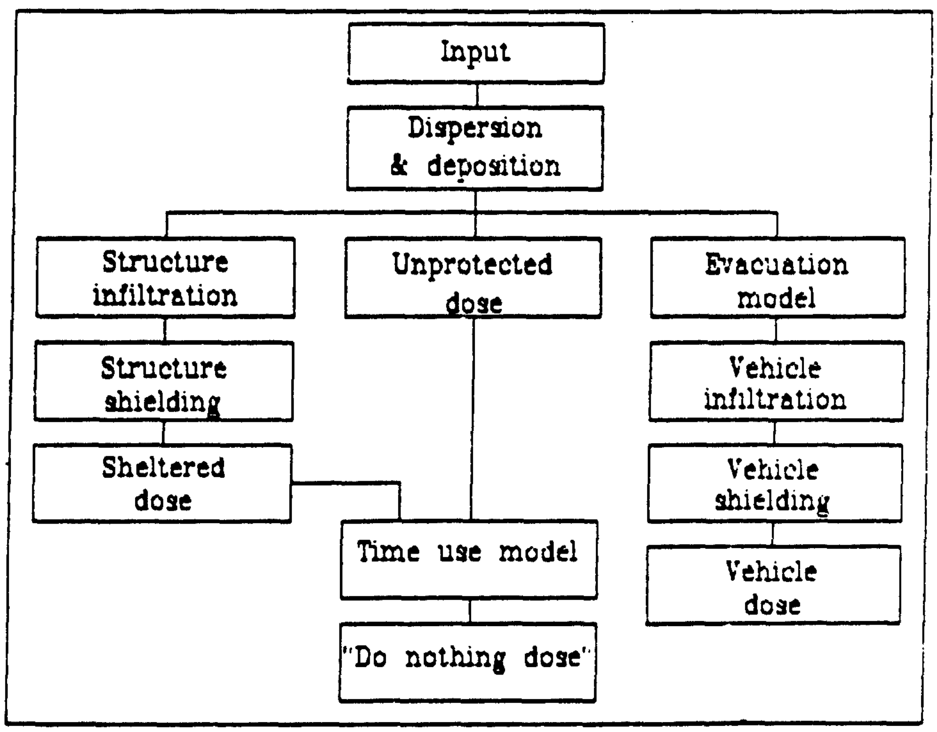

FIGURE 1 Flow Chart for a Radioactive Release Action Decision Model.

1.3 Background of the Shielding Problem

During the 1950's and early 1960's a great deal of work was done to predict the protection one would receive from weapon fallout by seeking shelter in a home, basement, factory or bomb shelter. This work was the result of the Federal civil defense policy of the time [1]. The result of this effort was the development of the Office of Civil Defense (OCD) Standard Method in several versions meant primarily for architects or for surveying existing buildings [2,3,4,5,6]. Very little additional work was done until the mid 1970s. The publishing of the Reactor Safety Study [7] prompted a new interest in structure shielding. In 1975, Z. G. Burson and A. E. Profio published Structure Shielding from Cloud and Fallout Gamma Ray Sources for Assessing the Consequences of Reactor Accidents [8]. For fallout protection data, they relied on the previous bomb fallout studies, and for cloud source protection data, they developed a point kernel integration technique. Their data were used by G. H. Anno and M. A. Dore in "The Effectiveness of Sheltering as a Protective Action Against Nuclear Accidents Involving Gaseous Releases", which was published by the EPA in 1978 [9]. That report raised the issue of infiltration of radioactive gases into the structures. Their report was further amplified by work done at Sandia Laboratories in 1977 and 1978 [10,11]. The Three Mile

Island accident prompted a new public interest in seeking protection from radioactive releases. In 1980, the National Bureau of Standards published Structure_Shielding_Against_Fallout_Gamma_Rays_From_Nuclear_Detonations [1]. This work is both a summary and a complete update of the previous fallout shelter work, but it deals only with fallout from a nuclear weapon. Nearly all the information in the open literature to date, including the works just mentioned, rely on gamma energy spectra either derived from bomb fallout, or from scenarios involving the release of a great amount of nuclear reactor core materials. As the TMI and SL-1 accidents pointed out, it is far more likely that only noble gases (which have a much lower energy spectra than weapon fallout) and a limited amount of volatile materials, such as iodine, will escape even from a severe accident [12,13]. Radioactive releases are also possible from other activities, such as transportation of spent reactor fuel, and manufacturing accidents involving medical sources. The_research_reported_here_is_an_effort_to_transfer_the_knowledge_gained_from_the_previous_weapon_fallout_shielding_work_to_realistic_protection_factors_for_possible_accidental_releases_whatever_the_released_spectrum_might_be.

1.4 Organization

This paper consists of a discussion of the rationale behind the selection of a point kernel model for both the fallout and cloud source conditions and a description of the component buildup factor, ground roughness and geometry models that were used. The results of the models are related to structures such as homes and vehicles and to the historical cases of TMI-2 and SL-1.

The three appendixes contain descriptions and FORTRAN listings of the programs developed to provide the required shielding data.

The protection factors reported here are called Dose reduction factors (DRFs). This term is adopted to prevent confusion with other terms such as shielding factors (SFs) and Protection Factors (PFs) which are defined differently by different researchers. In the strict sense, a DRF should be defined as the ratio of the actual dose received to the dose that would be received if there was no protection at all. Unfortunately, the relationship between dose and gamma energy for a standard individual is not easily defined for low energy gamma rays. The unavailability of this data required the use of exposure instead of dose in calculating the DRFs reported here. Because the DRF is a ratio of two exposures (or doses) taken at the the same gamma energies, the errors in using exposure instead of dose cancel each

other. The DRF, as used in this paper, is defined as the ratio of the protected exposure to the theoretical unprotected exposure.

CHAPTER II

STRUCTURE SHIELDING

2.1 Model Selection

The principle objective of this dissertation is to predict how the exposure from sources associated with a release of radioactive material varies as a function of the energy of the emitted gamma rays. The ability to predict gamma flux as a function of energy then became a prime factor in choosing a mathematical model. The ability to easily identify the components of the model and relate them to the physical world was also a prime selection criteria.

Shielding data have been calculated or experimentally found for a few shielding geometries, and for a very limited number of energies [14]. The enurgies used in the available literature are associated with weapon fallout or the postulated PWR-2 accident identified in the Reactor Safety Study (RSS) [15]. [The postulated PWR-2 accident "includes failure of the cooling systems, and core meltdown concurrent with a loss of containment spray and heat removal systems. Failure of the containment barrier occurs through overpressure causing a substantial fraction of the containment atmosphere to be released in a 'puff'" [16].]

While some good data are available for these high energy spectra, almost nothing is available for other energies. Thus a mathematical model only needs to determine how the shielding factors vary with energy, and then relate them to the known values for the bomb fallout spectra.

Three methods have been developed that can calculate the shielding provided by a structure: moments, Monte-Carlo, and point kernel integration. The method of moments is the basis for the "standard" method [2]. The standard method is very good for calculating the protection provided by a specific structure from a specific energy spectra, usually the 1.12 hour bomb fallout spectra. However, each new energy spectra requires the development of a set of tables, nomographs, and curves - making it very difficult to use the technique over a broad energy range.

The Monte-Carlo method is, in theory, an exact solution to the radiation transport equation and can be used for any geometry or energy distribution. It has the advantage of being able to find nearly exact answers to specific problems, however it is cumbersome to use, requires a great deal of computer time, and its implementation is difficult to relate back to the physical problem. The Monte-Carlo method is unnecessarily complex for the problem at hand.

The point kernel method has the advantage of being easily related to simple geometries. While it cannot

provide exact solutions to real problems, it can make reasonable estimates and is easily adapted to varying energies. The point kernel method can be used to provide the transforms necessary to get from known shielding values to values at other energies. For these reasons, the point kernel method was chosen as the math model in this dissertation.

Even with this seemingly simple choice, the method required a great deal of development in order to provide reasonably accurate estimates. First, buildup factors that are accurate over the necessary ranges of energy and mean free path had to be found. Second, an accurate method of combining the buildup factors in multi-region problems over a wide energy range had to be developed. And third, a method for calculating the effect of ground roughness on the attenuation factor for fallout sources had to be developed.

2.2 Point Kernel Methods

In Shielding, the treatment of uncollided photon flux is generally a simple exponential attenuation calculation. A point source of strength (S_o) (#/sec), in an infinite homogeneous medium characterized by a linear attenuation coefficient μ (1/cm), will have an uncollided flux ϕ (#/cm²/sec) at a distance R given by

$$\phi = S_o \cdot \exp(-\mu \cdot R)/(4 \cdot \pi \cdot R^2). \tag{2.1}$$

The factor $\exp(-\mu \cdot R)$ is due to material attenuation and the geometry factor $1/(4 \cdot \pi \cdot R^2)$ is due to the inverse square law. The combined factor

$$G(R) = \exp(-\mu \cdot R)/(4 \cdot \pi \cdot R^2) \tag{2.2}$$

is referred to as the point kernel. The uncollided flux for any geometry can be obtained, at least in principle, by integrating the point kernel over the geometry.

When the effect of collided flux is taken into account, the problem becomes a difficult transport problem. To get around this difficulty, a semiempirical factor, the buildup factor (BUF or B) is used to correct for the contribution from scattered flux. There are many types of buildup factors including the "number buildup factor", the "energy buildup factor", the "energy absorption buildup factor" and the "dose buildup factor". In this discussion only the dose buildup factor is of interest. The dose buildup factor is defined as the ratio of the total dose rate at a point to

the dose rate due to the uncollided flux at the same point. The point kernel is a function of the photon energy, shield thickness, and the atomic number of the shield material (Z) [17]. The point kernel for the flux at a distance R becomes

$$G(R) = B \cdot \exp(-\mu \cdot R)/(4 \cdot \pi \cdot R^2). \qquad (2.3)$$

Here the value of the calculated flux is weighted to account for the reduced dose rate due to the lower linear energy transfer rate of the lower energy collided photons. Because the total dose rate is always greater than the dose rate due to uncollided flux only, buildup factors are always greater than 1.

As explained in Section 1.4, even though the term "dose" is used throughout this dissertation, the programs developed here calculate exposure. This should not represent any real problem because this dissertation deals with the ratio of exposures which is equivalent to the ratio of doses (DRF).

2.3 Accurate Buildup Factors

Finding accurate equations for the required buildup factors can be difficult. The models require buildup factors over a range of energy from 15 KeV to 15 MeV and a range of mean free paths (mfps) from 0 to greater than 40 mpfs. Nearly all the works reporting buildup factor data were published before 1970. As late as 1968, even the most comprehensive works only reported data for 0.5 to 10.0 MeV and out to 20 mfps [18]. Further, even when data are available, the most accurate formulas commonly used can deviate from the true buildup factors by more than 60% [19]. The greatest deviations occur between 0.1 and 2.0 MeV, which, unfortunately, is where the most interest lies. The three most common formulas for estimating buildup factors are Taylor's formula (a three parameter, two term exponential equation), Berger's formula (a two parameter exponential equation), and a polynomial formula which usually has three terms, but is often used with two terms and as such is good only for thin shields [20,21].

Taylor's formula: (2.4)

$$B = A\cdot \exp(-a\cdot \mu\cdot r) + (1 - A)\exp(-b\cdot \mu\cdot r)$$

Berger's formula: (2.5)

$$B = 1 + a\cdot \mu\cdot r\cdot \exp(b\cdot \mu\cdot r)$$

Polynomial formula: (2.6)

$$B = \sum_{i=0}^{3} a_i \cdot (\mu\cdot r)^i$$

Two term polynomial formula (2.7)

$$B = 1 + k\cdot (\mu\cdot r)$$

A further complication, and a little reported fact, is that the parameters for the just mentioned formulas may have been calculated using criteria designed to prevent underestimation of doses [22]. In other words, data taken by engineers as accurately representing physical reality have been altered to prevent them from seriously underestimating doses. As an example, Taylor's formula at 0.5 MeV has a total deviation of approximately 44% over 0 to 40 mfps; parameters reported in the literature [23] cause a deviation of from +41.3% to - 5.4% instead of +22.% to -22.% [22]. Because one of the goals of this paper is to compare the exposure received for different spectra as accurately as possible to allow an intelligent selection of alternatives, data with this kind of inaccuracy cannot be used.

A much more accurate formula, along with the required parameters for water has recently been published by A. Foderaro and R. J. Hall [24]. This is a three term, five

parameter formula similar to Taylor's formula. The average deviation of this formula is reported to be less than 1.% at most energies and never exceeds 4.% (the maximum deviation is at 0.1 MeV and 40 mfps).

Three-exponential formula (2.8)

$$B = \sum_{i=1}^{3} A_i \cdot \exp(-\alpha_i \cdot \mu \cdot r)$$

where $A_3 = 1 - A_1 - A_2$.

The buildup factors for air and water as a function of energy and mean free path are very nearly identical [25]. This is because the average "Z" number of air and water are nearly the same. A comparison of the two buildup factors is shown in Figure 2 at 20 mfps. The error for fewer mfps is much less than at 20 mfps. Fortunately the greatest deviation between the air and water buildup factors occurs at large mean free paths where attenuation makes the error in calculating expoosures insignificant. The program used in this paper uses the three-exponential formula (equation 2.8) with the parameters given for water to find the buildup factors for air [24].

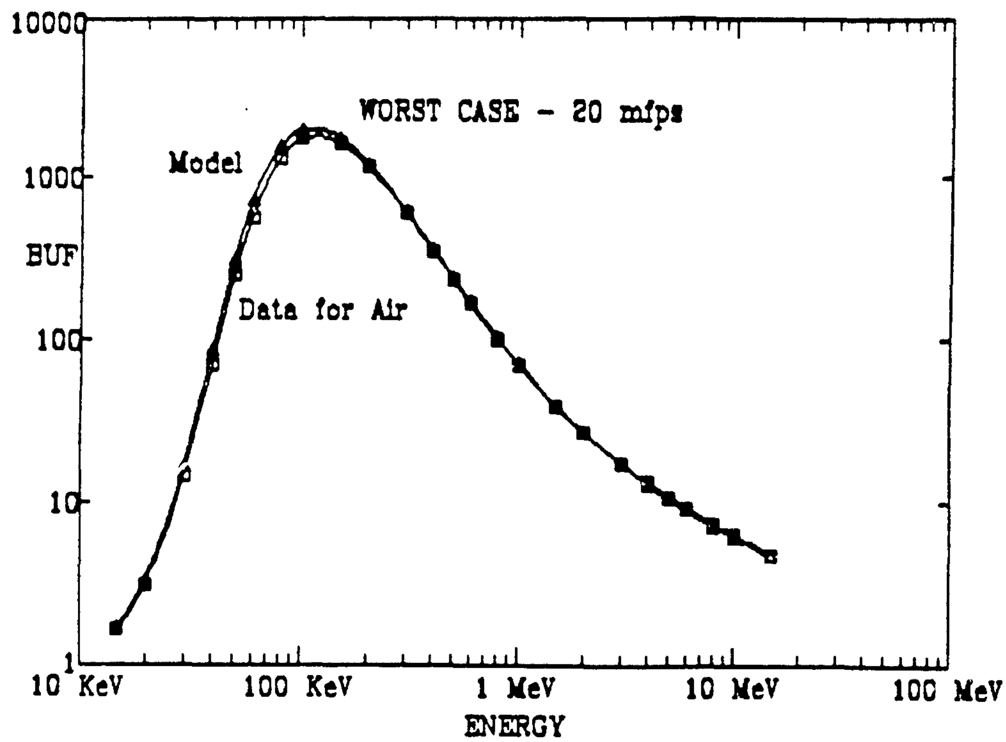

FIGURE 2 A Comparison of the Buildup Factors Calculated from the Three-Exponential Formula for Water with the True Buildup Factors for Air.

Finding accurate buildup factors for a general structure's walls and roof is also difficult. Fortunately, construction materials are almost completely constituted of low-Z elements and thus, after adjusting for density variations, wood and concrete are very nearly equivalent [26]. Therefore, the mass attenuation coefficients and buildup factors of what is referred to as "NBS" Concrete were chosen to represent building materials. The formula contains six non-linear terms and eleven parameters [27]. It was developed by the National Bureau of Standards and is the standard for concrete; as such there is no error associated with it as there would be if an approximation formula had been used. Using concrete as an approximation for building material in general is much more accurate than using the buildup factors for water (or compressed air) as is commonly done [28]. The practice of using the buildup factors for water seems to be a continuation of an earlier practice developed to avoid a limitation of the moments method where all materials are considered to be water or air of varying density [29,30]. However, the buildup factors for water can be more than 100 times that of concrete for large mean free paths and energies near 0.1-MeV [31].

All of the buildup factors used in the program are "Air Kerma Response Function" buildup factors. These buildup factors are meant to be used to calculate exposure and dose.

2.4 Combining Buildup Factors

A major problem in using the point kernel method occurs when the photons pass through more than one media. A single buildup factor must be found that represents the buildup through all the layers of material between the source and the detector. In order to understand this problem it is necessary to consider the definition of a buildup factor.

The buildup factor is the ratio between the detector response to the total radiation at a point of interest over the detector response to the uncollided radiation at the same point [32]. Buildup factors are necessarily a function of four variables: the composition of the material through which the radiation passes (usually just referred to as Z number dependence), the geometry of the source and the detector, the number of mean free paths (mfps) that the radiation passes through and, the energy of the uncollided radiation. By using mfps instead of physical distance, the formulas for calculating buildup factors are independent of material density. The number of mean free paths remain a function of material, density and distance. Buildup factors are calculated using the Monte-Carlo or moment methods, or found from empirical data. Usually the medium is assumed to be infinite.

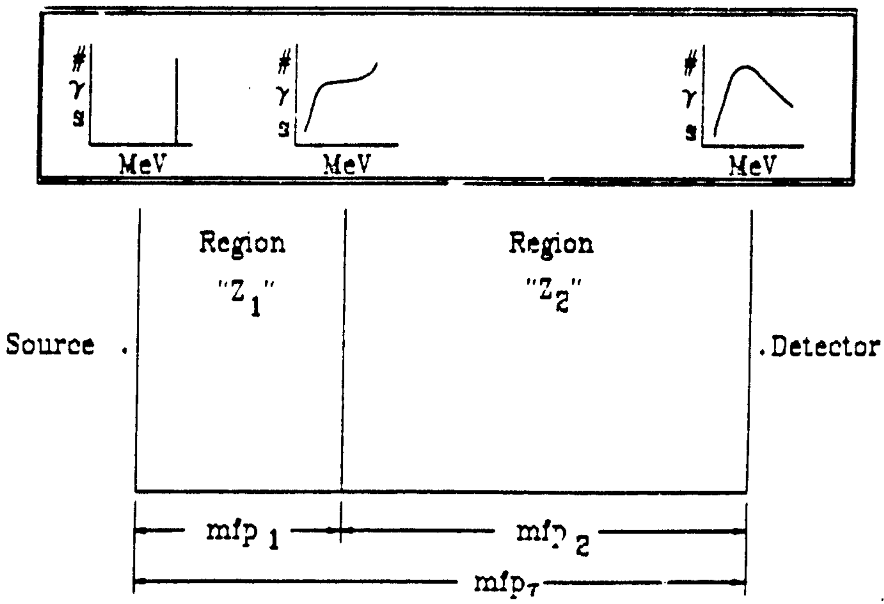

FIGURE 3 Two Region Geometry for Buildup Calculations

The equation for the dose from a simple point source in a continuous homogeneous infinite medium is:

$$D_R = D_O/R^2 \cdot B(E_O, mfp_T, Z) \cdot \exp(-mfp_T) \qquad (2.9)$$

Where: mfp_T = the number of mean free paths between the source and the detector;

R = the geometrical distance between the source and the detector in units of distance;

D_R = the dose at the detector;

D_O = the dose at a unit distance from the source in the absence of any medium in the units of dose times distance squared; and

$B(E_O, mpf, Z)$ or B = the Buildup factor as a function of source energy, mean free path, and material Z number.

By defining D_O at the same distance from the source as the detector, (this can be done because R is in arbitrary distance units) R becomes equal to 1 and the equation is simplified to:

$$D_R = D_O \cdot B(E_O, mfp_T, Z) \cdot \exp(-mfp_T) \qquad (2.10)$$

or:

$$B = B(E_O, mfp_T, Z) \equiv D_R/D_O \cdot \exp(mfp_T) \qquad (2.11)$$

If we take a continuous medium and break it into two regions (see Figure 3):

$$B = D_2/D_1 \cdot D_1/D_0 \cdot \exp(mfp_1) \cdot \exp(mfp_2). \tag{2.12}$$

But: $B(E_0,mfp_1,Z)$ = the buildup factor from point "0" to point "1"

$$= D_1/D_0 \cdot \exp(mfp_1). \tag{2.13}$$

Thus we can think of the buildup factor from point "1" to point "2" as

$$B(E_0,mfp_2,Z) = D_2/D_1 \cdot \exp(mfp_2) \tag{2.14}$$

and:

$$B = B(E_0,mfp_1,Z) \cdot B(E_0,mfp_2,Z)$$
$$\equiv B(E_0,mfp_T,Z). \tag{2.15}$$

Clearly buildup factors must be multiplied in order to be combined. The difficulty lies in finding $B(E_0,mfp_2,Z)$. For a continuous medium:

$$B(E_0,mfp_2,Z) \equiv B(E_0,mfp_T,Z)/B(E_0,mfp_1,Z). \tag{2.16}$$

$B(E_0,mfp_2,Z)$ represents the additional buildup from point 1 to point 2. It takes into account the buildup and shift in energy spectrum from point 0 to point 1 (see the insert in Figure 3). The problem becomes apparent when one realizes that buildup factors are only tabulated for continuous media. If the media in region "Z_1" and region "Z_2" are different, we can find $B(E_0,mfp_1,Z_1)$ from tables, but not $B(E_0,mfp_T,Z_{1,2})$ or $B(E_0,mfp_2,Z_2)$. Here $Z_{1,2}$ represents the

composite region made up regions Z_1 and Z_2. In fact the value of $B(E_o,mfp_T,Z_{1,2})$ is dependent on the geometry of the problem as well as the detailed composition of both regions. Thus we cannot exactly determine $B(E_o,mfp_T,Z_{1,2})$ by the point kernel method unless the same specific problem is first solved either empirically or by the Monte-Carlo method.

Several methods have been developed over the years for estimating $B(E_o,mfp_T,Z_{1,2})$. The most common method simply multiplies the buildup factor $B(E_o,mfp_1,Z_1)$ by $B(E_o,mfp_2,Z_2)$ [32,33,34,35,36]. This method overestimates the composite buildup factor $B(E_o,mfp_T,Z_{1,2})$ [32,35], and therefore gives an upper limit.

Another method developed by D. L. Broder [37] for a narrow range of energies is to combine the buildup factors as follows:

$$B(E_o,mfp_T,Z_{1,2}) = B(E_o,mfp_1,Z_1) + B(E_o,mfp_T,Z_2) - B(E_o,mfp_1,Z_2) \qquad (2.17)$$

The method can be extended to more than one region. Broder did not discuss the development of Equation 2.17 except to say that "it can be recommended for calculating buildup factors for heterogeneous media at energies near 1 Mev", and, "...it may be assumed that the derived equation is also applicable for large energies". It does fit his data, but overestimates the buildup factors at lower energies (see

Figure 3). Broder's method and a few slight variations of it are vary popular where more accurate combined buildup factors are sought but the restrictions on when they are to be used are seldom mentioned [32,33,34,35].

Another commonly used method takes only the larger of $B(E_o,mfp_1,Z_1)$ or $B(E_o,mfp_2,Z_2)$. This underestimates the buildup factor, but it does give a lower bound.

The method used here for estimating the combined buildup factor is derived from Equation 2.16. The buildup factor for region "Z_2" is estimated by taking the ratio of the buildup factor found by using the material of region "Z_2" and the total number of mean free paths from the source to the end of region "Z_2" divided by the the buildup factor found by using the material of region "Z_2" and the total number of mean free paths from the source to the beginning of region "Z_2":

$$B(E_o,mfp_2,Z_2) = B(E_o,mfp_T,Z_2)/B(E_o,mfp_1,Z_2). \tag{2.18}$$

This method takes into account the development of the spectrum as it penetrates region "Z_1" by assuming the spectrum would be similar to that developed if it penetrated the same number of mean free paths of material "Z_2". If the media in regions "Z_1" and "Z_2" are the same (or even if they are made of the same elements but with different densities) Equation 2.18 reduces to the identity Equation 2.16. In

fact this assumption should be very good for regions of similar Z number, because as shown by plots of the differential energy spectrum for water and aluminum due to mono-energetic gamma rays, there is little difference in the shape of the spectrum produced in materials of Z number less than 13 [38]. The "Z" number of concrete is usually taken as 13 also.

Determining the exact accuracy of this method would require empirical or Monte-Carlo solution. However, this method passes two important tests that are required of an accurate method. First, its results generally lie between the known upper and lower bounds over the entire energy range. The only exception is at approximately 150 KeV, where the shift in the photon energy spectrum that occurred in the first medium altered the BUF curve of the second medium as expected. Second, for the available data (at 1.25 MeV) agreement is very good as shown in Figure 4 where Border's data and his formula also agree. The method developed here is the only one that passes both tests.

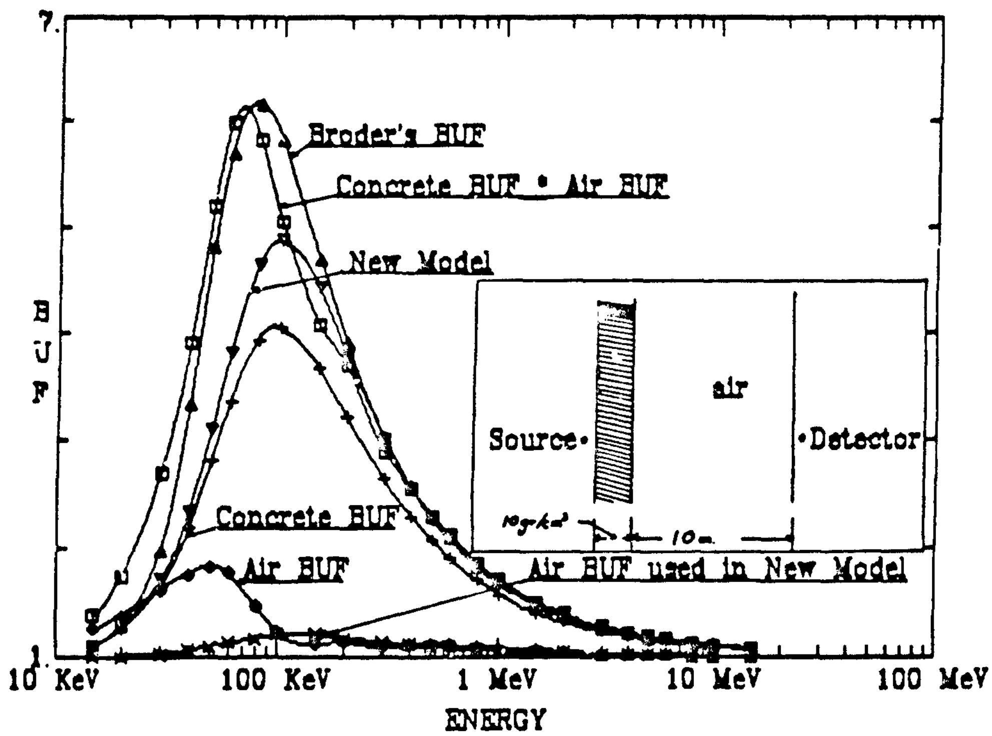

FIGURE 4 Comparison of Results of Methods of Combining Buildup Factors for a two region problem.

2.5 Comparison of Source Spectra

While it is not a purpose of this dissertation to speculate on the protection offered by a shelter for any particular release event, it is necessary to calculate the protection provided for a few well documented spectra in order to compare results and draw conclusions relevant to the current literature. How the spectra for comparison are obtained is of some interest. The programs used here require the source to be reported by each gamma energy and the fraction of disintegrations resulting in that energy for each curie emitted by the source.

For releases reported as curies of individual isotopes, the job is easy. The only assumption that needs to be made is that the isotopes are uniformly mixed. Even this assumption may be relaxed when the models used here are coupled with a dispersion model. Care must be taken that all daughter isotopes are found. Table 1 gives an example of this kind of release data. It contains the release reported for the first 33 hours of the Three Mile Island Accident in March 1979 [39]. In Table 2 the energy peaks for each of the isotopes and their daughters have been catalogued [40]. Table 3 shows the data reduced to a suitable spectra by multiplying the fraction of the isotope in the release by the fraction of disintegrations that result in that particular gamma photon energy. Similar

energies have been summed. Note that the iodine-131 plays an insignificant role in the cloud source; however, it comprises the entire ground source (Table 4). In a similar manner the fallout spectrum for the 1961 SL-1 accident can be found from the 10 Curies of I-131, 0.5 Curie of Cs-131 and 0.1 Curie of Sr-90 released [41]. Note that Sr-90 plays no role in the shielding calculation since it is a pure beta emitter. Bremsstrahlung is not included in the spectrum calculations due to the low average energies generated, high shielding factors at those energies, and the low bremsstrahlung yield in the low Z number materials involved.

When releases are reported as spectra in the literature, they are often reported in energy groups and as the relative energy content of the gamma rays emitted in each group. These spectra must be converted to energy groups and the relative number of gamma photons emitted in each group. Tables 6 and 7 [42] give examples of this type of conversion. In these tables, "f" is the fraction of the total photon energy contained in each energy group. To convert to the relative number of photons in each group, "f" is divided by the average energy of each group and renormalized to 1.0. The resulting fraction is used by the programs to calculate the dose reduction factors, but cannot be used to find the dose per Curie of release, unless the isotopic composition of the radioactive material is known.

This is because the number of curies required to produce a given number of photons is unknown.

A much easier way of obtaining spectra is to find them given in the way needed - by energy group and relative number of photons in each group as was found for the weapon fallout spectra given in Table 8 [43]. Again the dose per Curie released cannot be directly found, but the dose reduction factors can be calculated. When these spectra are used, the exposure for each average group energy is found and multiplied by the fraction of photons in that group. The results are summed to find the total exposure and divided by the similarly found unprotected exposure to obtain the dose reduction factor.

Figures 5 and 6 depict the relative energy of each of the six spectra discussed. In order to provide a visual comparison of the spectra, all six spectra were converted to energy groups.

TABLE 1

ISCTOPIC RELEASE FOR THE FIRST THIRTY-THREE HOURS

OF THE THREE MILE ISLAND ACCIDENT OF MARCH 1979 [39]

Isotope	Curies	Fraction
Xe-133	4.9 x 10**6	0.729
Xe-133m	1.2 x 10**5	0.018
Xe-135	1.5 x 10**6	0.223
Xe-135m	1.4 x 10**5	0.021
Kr-88	6.1 x 10**4	0.0091
I-131	1.908	0.0000003
total	6.72 x 10**6	1.0

TABLE 2

ENERGY PEAKS FOR ISOTOPES IN TABLE 1

Isotope	Energy(MeV)	Fraction of Disintegrations
Xe-133	0.081	0.37
Xe-133m	0.233	0.14
	0.081 (Xe-133)	0.37
Xe-135	0.250	0.91
	0.61	0.03
Xe-135m	0.527	0.80
	0.250 (Xe-135)	0.91
	0.61 (Xe-135)	0.03
Kr-88	0.028	0.07
	0.166	0.07
	0.191	0.35
	0.36	0.05
	0.85	0.23
	1.55	0.14
	2.19	0.18
	2.40	0.35
	0.898 (Rb-88)	0.13
	0.186 (Rb-88)	0.21
	2.68 (Rb-88)	0.023
I-131	0.80	0.026
	0.284	0.054
	0.364	0.82
	0.637	0.068
	0.723	0.016
	0.164 (Xe-131m)	0.0002

TABLE 3

ENERGY SPECTRA DERIVED FROM TABLES 1 AND 2

ENERGY (KeV)	Fraction of gammas per Curie of release
2680.	0.000209
2400.	0.00319
2190.	0.00164
1863.	0.00191
1550.	0.00127
898.	0.00118
850.	0.00209
610.	0.00732
527.	0.0168
360.	0.000455
250.	0.2220
233.	0.00252
191.	0.00319
166.	0.00637
81.	0.2764
28.	0.000637

Table 4

I-131 SPECTRUM (TMI PARTICULATES)

Energy (KeV)	Fraction of Gammas
723.	0.016
637.	0.068
364.	0.82
284.	0.054
164.	0.0002
80.	0.026

TABLE 5

SL-1 FALLOUT SPECTRUM [41]

Energy (KeV)	Source	Fraction of Gammas per Curie
723.	I-131	0.0151
662.	Cs-137	0.0401
637.	I-131	0.0642
364.	I-131	0.774
284.	I-131	0.0509
164.	I-131	0.00019
80.	I-131	0.0245

TABLE 6

RELATIVE SOURCE SPECTRA FOR A CLOUD SOURCE FROM A

REACTOR SAFETY STUDY PWR-2 EVENT [42]

E(MeV)	Eave	f	f/Eave	Fraction
0.01-0.1	0.05	0.033	0.660	0.3693
0.1-0.5	0.30	0.164	0.547	0.3059
0.5-1.0	0.75	0.197	0.264	0.1476
1.0-2.0	1.50	0.279	0.186	0.1041
2.0-3.0	2.50	0.327	0.131	0.0732
total		1.000	1.787	1.0

TABLE 7

RELATIVE SOURCE SPECTRA FOR A FALLOUT SOURCE FROM A

REACTOR SAFETY STUDY PWR-2 EVENT [42]

E(MeV)	Eave	f	f/Eave	Fraction
0.01-0.1	0.05	0.010	0.200	0.1696
0.1-0.5	0.30	0.086	0.287	0.2432
0.5-1.0	0.75	0.244	0.325	0.2759
1.0-2.0	1.50	0.386	0.257	0.2183
2.0-3.0	2.50	0.274	0.110	0.0930
total		1.000	1.179	1.0

TABLE 8

FINN-SIMMONS 1-HOUR WEAPON FALLOUT SPECTRA [43]

E(MeV)	Eave	Photon Fraction
0.0-0.05	0.025	0.0271
0.05-0.10	0.075	0.0137
0.10-0.20	0.150	0.0737
0.20-0.30	0.250	0.0476
0.30-0.40	0.350	0.0929
0.40-0.60	0.500	0.1373
0.60-0.80	0.700	0.1717
0.80-1.00	0.900	0.1627
1.00-1.33	1.165	0.0889
1.33-1.66	1.500	0.0957
1.66-2.00	1.830	0.0299
2.00-2.50	2.250	0.0397
2.50-3.00	2.750	0.0148
3.00-4.00	3.500	0.0042
4.00-5.00	4.500	0.0001
total		1.0000

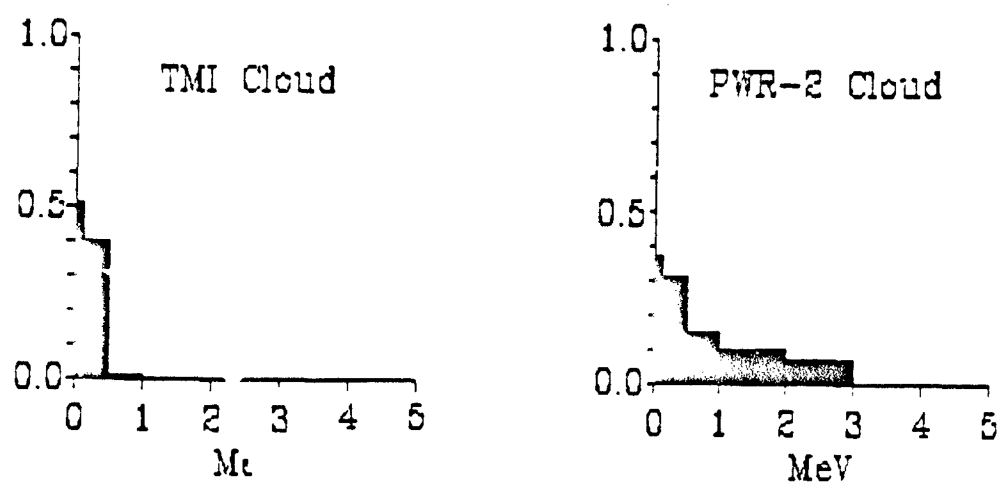

FIGURE 5 Comparison of Cloud Source Spectra.

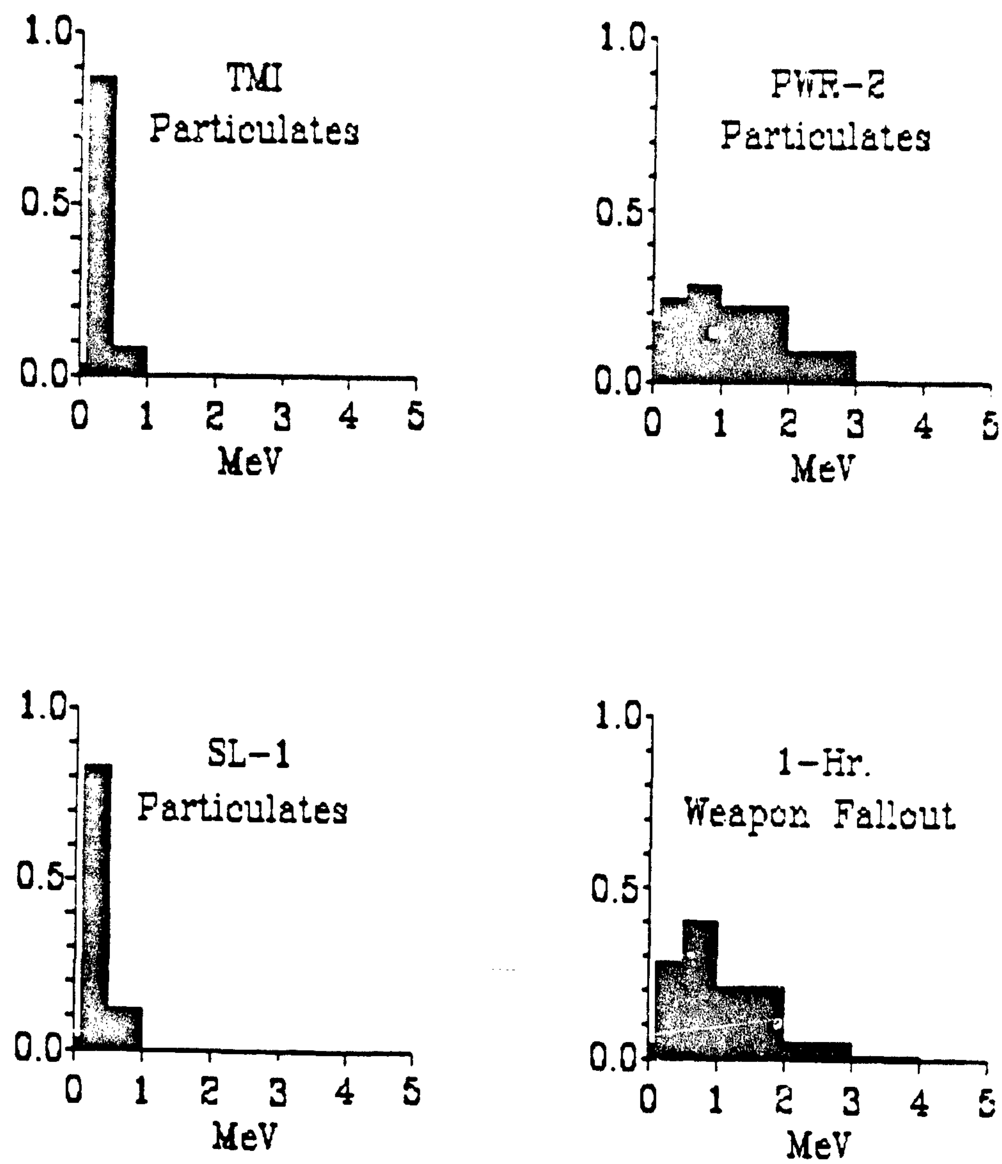

FIGURE 6 Comparison of Fallout Source Spectra.

2.6 Ground Effects

The hypothetical infinite smooth plane source assumed for point kernel integration over a disk source does not exist in nature. The fallout particles distribute themselves over the real terrain surface. Small surface irregularities, such as grass, gravel and concrete are usually called ground roughness in the shielding literature. For an infinite plane source, most of the gamma rays originate from large distances and travel through small grazing angles to the surface; irregularities in the surface cause those rays to be attenuated as they begin their journey. Larger surface irregularities, such as hills, washes and buildings are called terrain effects. These large irregularities nearly always reduce dose rates (by as much as 50% "for a person standing on top of a small steep hill that falls away in all directions....because the hill hides much of the fallout beyond the immediate area.") [44]. However these large effects are not general in nature, being peculiar to specific buildings and situations, and are therefore not considered in this model. This dissertation is concerned with modeling effects that are more general in nature i.e. the shielding provided by lawns, streets, etc.

2.6.1 Previous Models

In 1968, the Defense Civil Preparedness Agency [45] published reduction factors to be applied to various ground roughness conditions for a fallout source. These data are repeated in Table 9. These data indicate that ground roughness can reduce the dose rate by as much as 50% compared with 1 meter above the standard hypothetical smooth plane source, assuming that the same amount of fallout is uniformly deposited in both cases.

The simplist model, and the one most commonly found in the literature, applies the above factors directly to shielding factors found for buildings, without regard to the fallout source [44,46]. However, because the reduction factor is caused by a portion of the gamma photons passing through surface irregularities as they start their journeys, the reduction factors must be source energy dependent.

Another possible model was suggested by C. M. Huddleston in 1964 when he observed that the ground roughness effect of various Nevada terrains on fallout from an atmospheric bomb test was equivalent to raising his detector 20 to 40 ft [47]. While lifting the detector, and thus increasing the attenuation caused by air and distance will give a source energy dependent model, it is not satisfactory for the following reasons. First, that model exposes all the gamma rays to the additional material, while

in the real situation only that fraction of the photons behind a surface irregularity would be effected by it. This would effect the resultant spectrum at the detector. Second, that model causes a relatively greater attenuation of photons originating near the detector than those originating at a large distance, yet the gamma rays originating from long distances travel through small grazing angles to the surface and thus should be more greatly attenuated than photons originating near the detector which have a nearly unobstructed line of sight.

TABLE 9

GROUND EFFECT DOSE REDUCTION FACTOR

FOR 1.12 HR. WEAPON FALLOUT [45]

Ground Roughness Condition	Reduction Factor
Smooth plane (hypothetical)	1.00
Paved areas	1.00 to 0.85
Lawns	0.85 to 0.75
Gravelled areas	0.75 to 0.65
Ordinary plowed field	0.65 to 0.55
Deeply plowed field	0.55 to 0.47

2.6.2 Proposed Model

There is very little information upon which to base a ground roughness model. In fact, the reference given in Table 9 gives only one datum point for one particular spectrum (the 1.12 Hr. fallout spectrum) for each of five surface types. In order to make the best use of available data and research, a model must be very general in nature - but must have sufficient data available to define all its parameters. Obviously the one datum point available will only allow the fitting of one parameter. Any additional parameters must be defined by other means.

The model used in this paper was developed from one used to compare the angular distribution of dose rate over a plowed dry lake bed to that over a smooth dry lake bed after fallout from the explosion of a nuclear device [48]. The model reflects the geometry of a plowed field, see Figure 7, but the three parameters used by the model make it quite general in nature. The parameters are: Ψ , the trough angle; w, the trough width; and d, the width of the remaining flat surface. The major difference between the model used in this paper and the model it is derived from is that the existing model assumed the concentration of fallout was equal on all surfaces regardless of tilt, while the model used here assumes that the fallout is uniform on the horizontal projection of the surface. The use of the two

models is also different. While the previous model was used to predict specific dose values, the model used in this paper is used to predict dose values at different energies. Instead of finding a specific dose reduction value from known parameters, the model must use known dose reduction values to find the unknown parameters.

The problem is to determine the values of three parameters when only one datum point (Table 9) is given for each surface condition. Because the model is used as it is, this problem can be solved.

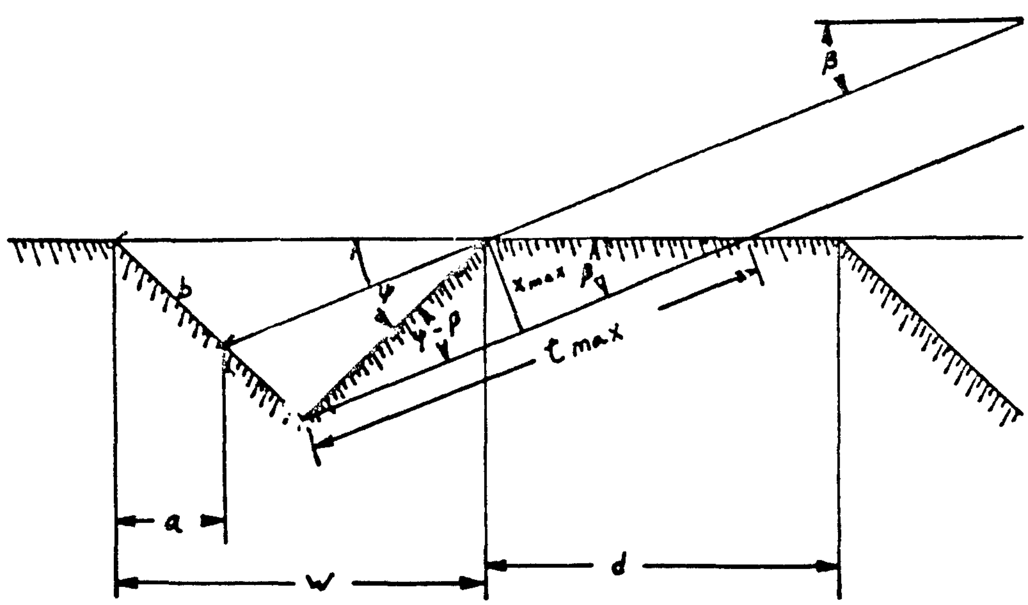

FIGURE 7 Geometry of the Ground Effects Model

The concept of a "half-shadow" angle was introduced by Yu. A. Izrael in 1963 [49]. The ratio d/w, for a given value of Ψ, can be found, at least in many cases, from the half-shadow angle ($\beta_{\frac{1}{2}}$). The half-shadow angle is defined as: the angle above the horizontal from which the ground is illuminated causing half the surface to be in shadow when viewed from above. As an example: "when meadow land is illuminated from an angle of 1-degree above the horizontal and photographed from above, about 50 percent of the surface is in shadow [50]. The half-shadow angle $\beta_{\frac{1}{2}}$ can be thought of as being measured from the same reference as β in Figure 7. The relationship between d/w, $\beta_{\frac{1}{2}}$ and Ψ is as follows:

$$d/w = 1. - 2. \cos(\Psi) \cdot \sin(\beta_{\frac{1}{2}})/\sin(\Psi+\beta_{\frac{1}{2}}) \quad \text{for } \beta_{\frac{1}{2}} < \Psi. \qquad (2.19)$$

As can be seen a $\beta_{\frac{1}{2}}$ does not exist if d is greater than w --as in the case of the previously referenced plowed dry lake bed where d was 18 inches and w was 12 inches [48]. However for the more usual cases $\beta_{\frac{1}{2}}$ does exist. In fact it has been demonstrated that $\beta_{\frac{1}{2}}$ is proportional to the dose reduction factor [49]. Yu. A. Izrael's data give the following equation for $\beta_{\frac{1}{2}}$ where η is the dose reduction factor:

$$\beta_{\frac{1}{2}} = 16.43 - 19.05\eta \quad \text{degrees.} \qquad (2.20)$$

Izrael's data for $\beta_{\frac{1}{2}}$ and η for various ground conditions are given in Table 10.

TABLE 10

HALF-SHADOW ANGLE AND DOSE REDUCTION FACTOR

FOR VARIOUS GROUND TYPES [49]

Ground Type	$\beta_{\frac{1}{2}}$, degrees	η (DRF)
Very flat, virgin grassy region (meadow, clearing)	1.0	0.81
Very flat region of arid steps	1.7	0.77
Arid steps	3.0	0.69
Cultivated field	5.0	0.60

Because the model is used as it is, to find the parameter w that gives a given dose reduction for a given spectrum, the value chosen for ψ makes very little difference in the results for varying energies. The dose reduction factors over a plane with no structure present were compared over a wide range of ψ's (15 to 45 degrees) and half-shadow angles (1 to 5 degrees). The results show that the differences are insignificant for varying ψ's for energies above 80 KeV (see Figures 8 and 9). When a small central void was inserted in the plane, representing the removal of the ground source under a structure (the fallout falling on a structure is accounted for as a roof source), the differences are even smaller (Figure 10). And when a wall is added the differences become totally insignificant for all energies as shown in Table 11. What happens is that a specific dose reduction factor is specified for a specific gamma spectrum (in this case 0.81 for Co-60 [49]), ψ and $\beta_{\frac{1}{2}}$ or d/w are chosen (ψ and $\beta_{\frac{1}{2}}$ determine d/w) and the "Ground Factor" program (see Appendix A) iteratively determines a value of w such that the DRF equals the given value. The values of w, d/w and ψ are used in the "Fallout" program (Appendix B) to determine the DRF for other conditions where structures are present. For different values of ψ and a given $\beta_{\frac{1}{2}}$, the program simply finds a different value of w -- which results in very nearly the same DRF vs Energy curves.

The only significant differences (for flat planes, see Figures 8 and 9) are at low energies where the attenuation of building walls is so great that the variance in the DRF caused by small changes in ground effects is no longer significant, as shown in Table 11.

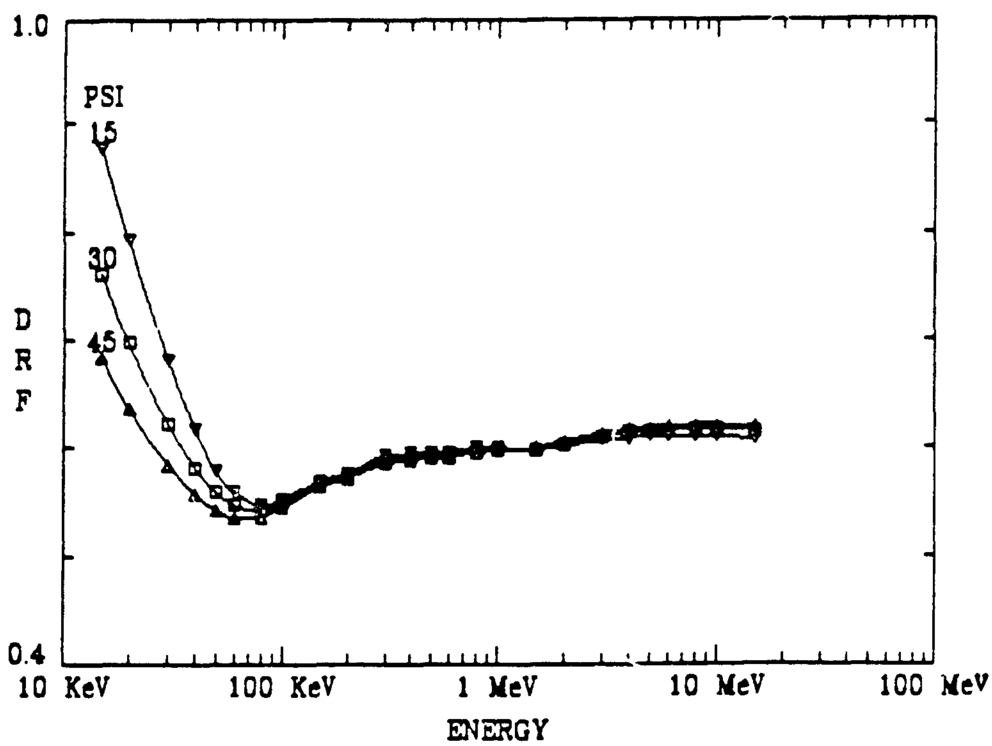

FIGURE 8 Dose Reduction Factors for a Half-Shadow Angle of 1 Degree over an Infinite Plane

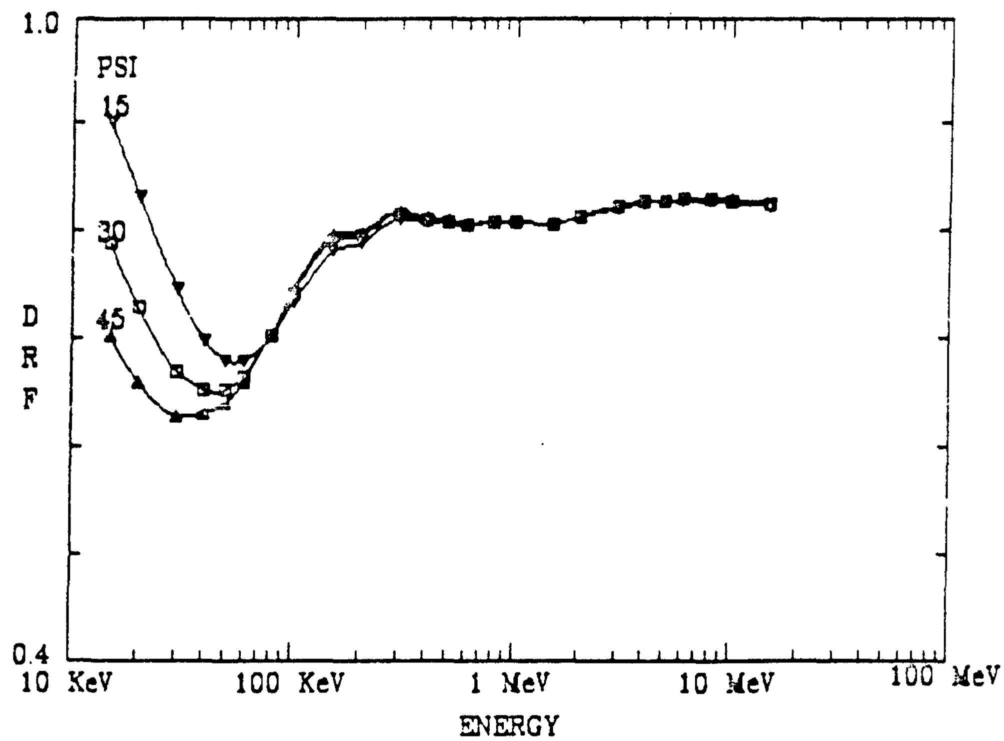

FIGURE 9 Dose Reduction Factors for a Half-Shadow Angle of 5 Degrees over an Infinite Plane

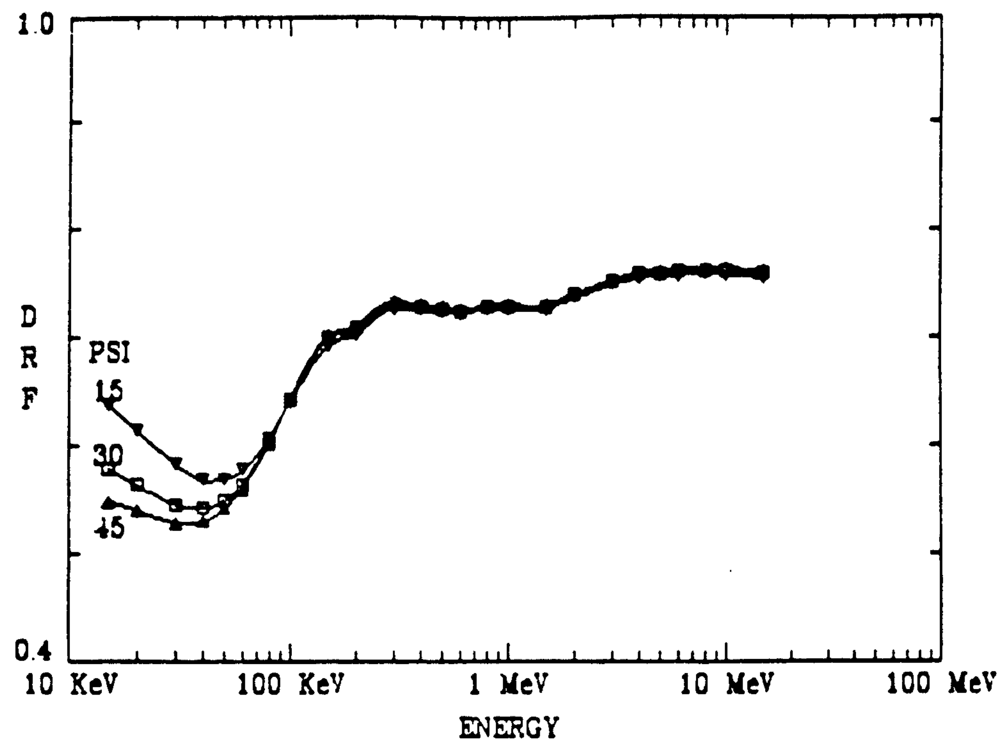

FIGURE 10 Dose_Reduction_Factors_for_a_Half-Shadow_Angle_of 1_Degree_over_an_Infinite_Plane_with_a_Central_Void_with_a_5 meter_Radius

TABLE 11

EFFECT OF VARYING THE TROUGH ANGLE ON THE

DOSE REDUCTION FACTOR FOR A SMALL HOUSE

ON A LAWN

Energy (KeV)	DRF for ψ = 45 deg.	DRF for ψ = 15 deg.	Percent difference
15000.	0.529	0.526	0.584
10000.	0.533	0.530	0.574
8000.	0.533	0.530	0.561
6000.	0.529	0.526	0.535
5000.	0.524	0.522	0.522
4000.	0.521	0.519	0.519
3000.	0.508	0.506	0.506
2000.	0.487	0.486	0.486
1500.	0.471	0.471	0.471
1000.	0.458	0.458	0.037
800.	0.452	0.452	-0.044
600.	0.444	0.445	-0.109
500.	0.442	0.443	-0.201
400.	0.439	0.440	-0.267
300.	0.433	0.434	-0.347
200.	0.379	0.400	-0.645
150.	0.359	0.362	-0.866
100.	0.244	0.248	-1.785
80.	0.157	0.162	-2.738
60.	0.0592	0.0617	-4.247
50.	0.0208	0.0220	-5.390
40.	0.00215	0.00230	-7.010
30.	0.342E-5	0.384E-5	-12.569
20.	0.117E-16	0.117E-16	0.0
15.	0.0	0.0	0.0

The Fallout program needs a representative value for the number of mean free paths that the ground-attenuated gamma rays pass through. It also requires the fraction of gammas that pass through the ground. The fraction of gammas that pass through the ground is:

$$(a + w)/(d + w). \qquad (2.21)$$

where:

$$a = w \cos(\psi) \cdot \sin(\beta)/\sin(\psi+\beta). \qquad (2.22)$$

The problem is in finding a representative value of t (see Figure 7). Choosing the average value of t works very well. The maximum value of t is:

$$t_{MAX} = w \cdot \sin(\psi)/(2 \cdot \cos(\psi) \cdot \sin(\beta)). \qquad (2.23)$$

The average value of t is:

$$t_{AVE} = t_{MAX}/2. \qquad (2.24)$$

In order to find a representative value of t (t_{REP}), the ground buildup and attenuation must be considered. Therefore the mean value of the kernel was found over the integral from x to x_{MAX} (Figure 7) and a value of t was iteratively found such that its kernel and the mean just found were equal.

$$\frac{\int_0^{X_{max}} B(E,\mu \cdot t(x))\ \exp(-\mu \cdot t(x)) \cdot dx}{\int_0^{X_{max}} dx} = B(E,\mu \cdot t_{REP}) \cdot \exp(-\mu \cdot t_{REP}) \tag{2.25}$$

Where

$$x_{MAX} = W \cdot \sin(\Psi-\beta)/(2 \cdot \cos(\Psi)) \tag{2.26}$$

and

$$t(x) = \cot(\Psi-\beta) + \cot(\beta)$$
$$= x \cdot \sin(\Psi)/(\sin(\beta) \cdot \sin(\Psi-\beta)) \tag{2.27}$$

The results are given in Table 12 and are compared to the results obtained by using t_{AVE} as the representative value of t. Clearly there is no significant error in using t_{AVE}. However there is a significant savings in computer time. Again the program simply finds a value of w such that the given DRF is obtained. Using t_{REP} instead of t_{AVE} simply changes the value of w -- but not the resulting DRFs.

TABLE 12

EFFECT OF USING T_{AVE} VS T_{REP} IN DETERMINING

THE DOSE REDUCTION FACTOR FOR VARYING ENERGIES

OVER A MEADOW LAND

Energy (KeV)	DRF for t_{REP}	DRF for t_{AVE}	Percent difference
15000.	0.832	0.828	0.41
10000.	0.833	0.831	0.35
8000.	0.834	0.832	0.31
6000.	0.834	0.831	0.26
5000.	0.833	0.831	0.24
4000.	0.832	0.830	0.19
3000.	0.826	0.825	0.15
2000.	0.817	0.816	0.087
1500.	0.809	0.808	0.032
1000.	0.811	0.811	-0.005
800.	0.810	0.811	-0.049
600.	0.807	0.808	-0.13
500.	0.811	0.812	-0.17
400.	0.813	0.815	-0.25
300.	0.817	0.820	-0.40
200.	0.797	0.802	-0.62
150.	0.793	0.799	-0.78
100.	0.745	0.748	-0.48
80.	0.705	0.706	-0.091
60.	0.665	0.662	0.44
50.	0.649	0.642	1.03
40.	0.644	0.633	1.75
30.	0.647	0.631	2.48
20.	0.675	0.662	1.91

2.6.3 Results of ground roughness model

The buildup factors and mass attenuation coeficients for concrete are used in the model to represent the ground surface. The "ground factor" is determined by iterative means using the Finn-Simmons 15-group, 1-hour fast fission delayed gamma ray spectrum which is representative of a typical bomb fallout spectrum [51].

Table 13 gives the necessary values of d/w and w to obtain the DRFs given in Table 9. The trough angle ψ is assumed to be 45 degrees.

Of course, the ground roughness shielding factor cannot be used directly on the disk source kernel. First the total buildup factors for both the direct and indirect photons must be determined for the ground, outside air, building walls, and inside air as demonstrated in the section of this paper on combining buildup factors. In this section, the building itself was left out (except where the insignificance of varying trough angles was discussed); only attenuation by the ground and air was considered. The total effect of the ground factor on the attenuation provided by a building will be discussed in Chapter 3. A listing and description of the program that finds the ground factor w is given in Appendix A.

TABLE 13

SUGGESTED GROUND EFFECT DOSE REDUCTION FACTORS

Surface	w	d/w	ψ degrees
Smooth plane	0.	1.	45.
Paved Areas	0.394	1.	45.
Lawns	2.370	0.959	45.
Gravelled Areas	7.468	0.897	45.
Plowed field	25.821	0.839	45.

2.7 The Fallout Model

The fallout source program models a structure as having cylindrical walls and a flat roof. The error in assuming the building is round is small and is not energy dependent [52]. The purpose is not to accurately predict the dose reduction factor for any particular building, rather to predict how that dose reduction factor will change with sources of different energies. The reference position is taken as 1 meter off the floor in the center of the structure. Infinity is taken as 12 mfps. The program was tested to prove that the error in only integrating to 12 mfps is less than 0.001%. The program does three integrations: One for the reference unprotected exposure; one for the exposure from material deposited on the roof; and one for the exposure from material deposited on the ground.

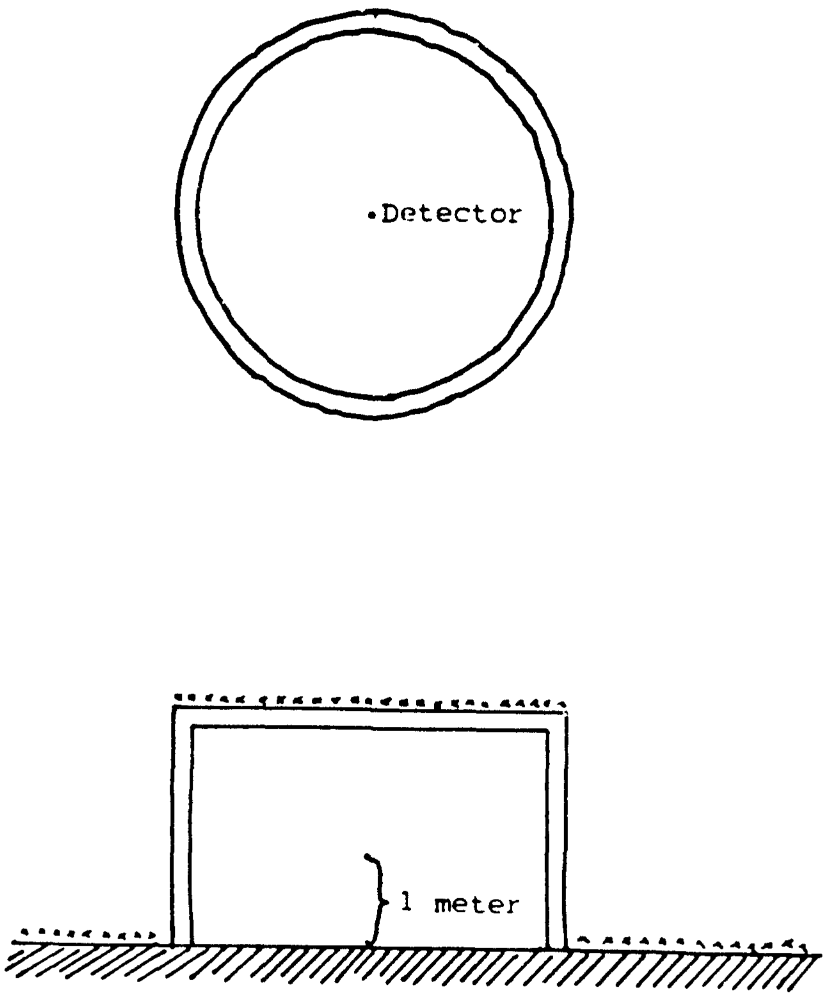

FIGURE 11 Geometry of the Fallout Program Model

The point kernel for exposure from a disk source, as in the case of either the roof, floor, or ground (see Figure 11), is:

$$G(r) = 0.5 \cdot k \cdot B\ r/(r^2 + a^2) \cdot \exp(-mfp) \cdot dr \qquad (2.28)$$

where: "r" is the incremental radius of the disk;

"a" is the length of the normal from the center of the disk to the detector;

"B" is the appropriate buildup factor for shield (roof or wall) and air combined;

"k" is the energy dependent conversion constant that converts "flux" to exposure;

and, "mfp" is the total number of mfps from the ring of integration to the detector.

The kernels are integrated using a form of Simpson's rule using rings of varying width to reduce computer time.

The program requires the input of the "equivalent height", "equivalent radius", wall mass thickness, roof mass thickness and the ground factors ψ (degrees), d/w, and w as discussed in section 2.6. Values for the mass thickness of the walls and roof are given in the literature [53]. The mass thickness of lightly constructed, wood frame houses varies from about 5 to 17 gr/cm^2 with a median value of about 10 gr/cm^2. For brick and block houses the mass thickness varies from about 10 to 32 gr/cm^2 with a median of about 22 gr/cm^2. The mass thickness of a 1 foot thick

concrete wall is about 61 gr/cm^2. The equivalent height of a structure may be found by integrating the uncollided gamma photon path length over the structure's dimensions or estimated for reasonably square structures by finding the radius of a circle with an equivalent area as the structures floor plan.

The program calculates the unprotected exposure, the exposure from sources on the roof and the exposure from sources on the ground. It then calculates the DRF for source energies from 15 KeV. to 15 MeV. and for the RSS PWR-2 Fallout, the One Hour Weapon Fallout, the TMI Fallout, and the SL-1 Fallout Spectra. Included in the output is the exposure that would be received from fallout internal to the structure if the fallout was in the same concentration as outside the structure. The internal exposure assumes no shielding. However internal fallout is not considered in the calculation of the DRFs.

A listing and description of the Fallout program is given in Appendix B. Table 14 gives a typical output from the Fallout program. The results of the Fallout program will be discussed in the next chapter.

TABLE 14

TYPICAL OUTPUT OF FALLOUT PROGRAM

Small Wood House on Lawn. 21 August 1984

Integration to 12 MFPs in air.
Detector is 1 meter above smooth plane
Equivalent radius of structure = 5.000 meters
Equivalent height of structure = 5.000 meters
Wall mass thickness = 10.000 gr/cm2
Roof mass thickness = 10.000 gr/cm2
The Ground Factors are:
The trough angle PSI = 45.0000 degrees
The charactoristic trough width W = 2.3698
The ratio of flat to trough D/W = .9590

E(KeV)	UNPROTECTED	ROOF	GROUND	TOTAL EXP.	ROOF CONT.	DRF	RATIO TO 1.12 Hr.	INSIDE
1.12 Hr.	14.83	.9441	5.807	6.751	.1398	.4553	1.000	4.443
RSS-Fallout	14.64	.9198	5.752	6.672	.1379	.4557	1.001	4.347
TMI-Fallout	7.319	.4716	2.560	3.032	.1556	.4319	.9485	2.141
SL1-Fallout	7.134	.4779	2.609	3.087	.1548	.4327	.9503	2.175
15000.0	138.4	8.772	63.82	72.59	.1208	.5244	1.152	39.23
10000.0	100.9	6.482	46.77	53.25	.1217	.5278	1.159	28.73
8000.0	84.19	5.448	38.98	44.43	.1226	.5277	1.159	24.10
6000.0	67.70	4.401	31.08	35.48	.1240	.5241	1.151	19.50
5000.0	59.49	3.872	27.02	30.90	.1253	.5194	1.141	17.24
4000.0	50.59	3.322	22.81	26.13	.1271	.5165	1.134	14.75
3000.0	41.60	2.698	18.23	20.92	.1290	.5030	1.105	12.20
2000.0	31.63	2.011	13.25	15.26	.1318	.4826	1.060	9.304
1500.0	25.91	1.614	10.48	12.09	.1334	.4668	1.025	7.594
1332.0	23.42	1.472	9.398	10.87	.1354	.4642	1.019	6.922
1173.0	21.01	1.338	8.341	9.671	.1375	.4602	1.011	6.267
1000.0	18.34	1.166	7.152	8.318	.1402	.4534	.9958	5.532
800.0	15.15	.9711	5.802	6.773	.1434	.4470	.9817	4.600
662.0	12.75	.8214	4.825	5.646	.1455	.4428	.9726	3.860
600.0	11.66	.7510	4.375	5.126	.1465	.4395	.9651	3.524
500.0	9.644	.6345	3.584	4.219	.1504	.4375	.9607	2.939
400.0	7.644	.5135	2.803	3.316	.1548	.4338	.9528	2.335
300.0	5.533	.3828	1.982	2.365	.1619	.4274	.9386	1.696
200.0	3.688	.2370	1.209	1.446	.1639	.3922	.8614	1.056
150.0	2.587	.1573	.7596	.9169	.1715	.3545	.7785	.7277
100.0	1.819	.7204E-01	.3661	.4381	.1644	.2408	.5288	.4645
80.0	1.661	.3876E-01	.2199	.2586	.1499	.1557	.3420	.4046
60.0	1.609	.1206E-01	.8242E-01	.9447E-01	.1276	.5871E-01	.1289	.4061
50.0	1.629	.3791E-02	.2992E-01	.3371E-01	.1125	.2069E-01	.4545E-01	.4545
40.0	1.739	.3695E-03	.3348E-02	.3718E-02	.9940E-01	.2137E-02	.4694E-02	.5854
30.0	2.075	.8638E-06	.6202E-05	.7066E-05	.1222	.3485E-05	.7478E-05	.9195
20.0	2.754	.3208E-16	.0000	.3208E-16	1.000	.1165E-16	.2559E-16	1.769
15.0	3.145	.0000	.0000	.0000	.8889E+33	.0000	.0000	2.540

2.8 The Cloud Source Model

The cloud source program used here models the structure as a hemisphere (see Figure 12). The exact height of the reference position for this volume source is of little or no consequence [54]. Therefore the reference position is taken as ground level. The basic source configuration is taken as semi-infinite because the ground excludes its lower half. Infinity is taken as 12 mfps. The program was tested to prove that the error in only integrating to 12 mfps is less than 0.01%. The error would be less than 0.0007% except that the buildup factors are large at large mfps. There are no ground roughness or terrain effects for a cloud source. The "Cloud" program (Appendix C) assumes the radioactive material is uniformly distributed in the cloud. This assumption may be relaxed when the program is combined with a dispersion model.

The point kernel for a hemispherical structure in a semi-infinite uniformly distributed cloud source is particularly simple:

$$E = \int_{a}^{\infty} k \cdot B_{COMB} \cdot \exp(-mfp_{w} - \mu \cdot r) \cdot 2 \cdot \pi \cdot r^{2} / (4 \cdot \pi \cdot r^{2}) \, dr \tag{2.29}$$

Which reduces to:

$$E = k/2 \cdot \exp(-mfp_w) \cdot \int_0^{\infty} B_{COMB} \cdot \exp(-\mu \cdot r) \cdot dr \tag{2.30}$$

The buildup factor has three regions: (1) the air between the hemispherical cloud shell (see Figure 12) and the building; (2) the structure dome and; (3) the interior air. Thus as discussed in section 2.4, the combined buildup factor becomes:

$$B_{COMB} = B_{AIR}(r) \cdot B_{WALL}(r + t)/B_{WALL}(r) \cdot B_{AIR}(r + t + a)/B_{AIR}(r + t). \tag{2.31}$$

Here "r", "t", and "a" represent the air between the structure and the shell of integration, the roof and walls, and the interior air respectively. B_{AIR} is the buildup factor for air and B_{WALL} is the buildup factor for the walls. The thickness of the walls in mean free paths is represented by mfp_w.

Equation 2.30 is integrated using Simpson's rule. The integration is done in regions varying from 0.2 mfp to 3.0 mfps in width to reduce computer time. The total integration error is less than 0.01%. Table 13 gives typical results for a structure with an equivalent radius of 5 meters and walls 10 gr/cm² thick.

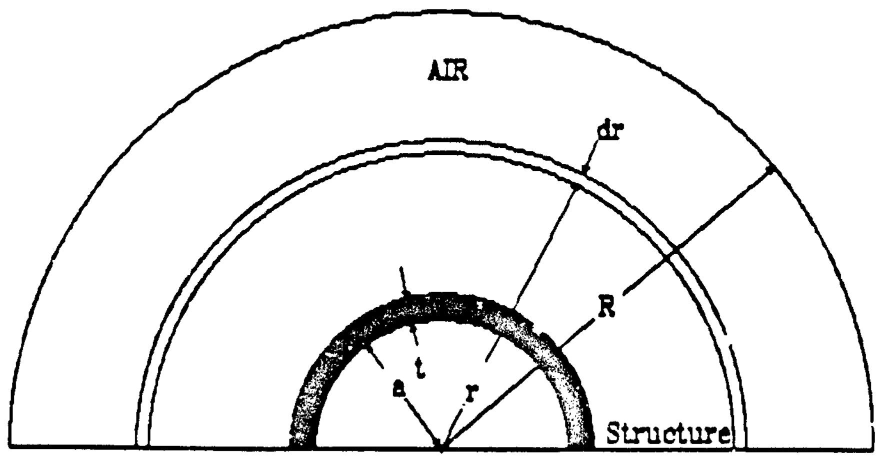

Figure 12 Cloud Exposure Calculation Geometry.

Burson and Profio presented data showing that for lightly constructed wood frame houses the wall mass thickness varies from about 5 to 17 gr/cm^2 with a median value of about 10 gr/cm^2; and for brick and block houses from about 10 to 32 gr/cm^2 with a median value of about 22 gr/cm^2 [55]. They also assumed that the roof and wall are of equal thickness - which seems reasonable for new, energy efficient construction. Their data were used for their ground source model, and should be valid for a cloud source also. However, estimates as low as 3.4 gr/cm^2 appear in the literature [56]. The 10 gr/cm^2 figure was chosen as representative of small wood frame houses and 22 gr/cm^2 as representative of brick faced houses. This discrepancy is mentioned not to pass judgment, but to explain why the numbers arrived at here may be different than those based on other works [57,58]. It is not the purpose of this paper to calculate protection factors, but to show how they vary with energy.

This paper is not the first to use a hemispherical shell model to calculate protection factors for cloud sources using point kernels [54]. There are several important differences however. First of all, the model used here integrates to 12 mfps; the referenced model only goes to 3 mfps. For a disk source, 3 mfps might be far enough, however with a volume source there is no 1/R factor, thus 3

mfps excludes more than 5% of the source [exp(-3) = .0498]. When the high buildup factors from these distances are included, the error becomes significant. Second, the previous model uses the buildup factors for water for the walls, this model uses concrete. Third, the previous model uses the linear formula for calculating the buildup factors for the air outside the structure. As already discussed, that formula is only good for thin shields. Fourth, that model multiplies the two buildup factors together, rather than combining them - thus introducing a conservatism. Fifth, the previous model ignores buildup and attenuation by air interior to the structure.

The hemispherical cloud model is easily extended to include cases where the cloud is limited in size, either in height by an elevated inversion layer or similar atmospheric phenomenon; or in radius as it might be if the structure were near the source. In the first case, the integration is carried out as with an infinite cloud, however those shells [see Figure 12] that are partially outside the height limit are modified by a factor of h/r, where h is the height of the top of the cloud, and r is the radius of the shell. This factor gives the fraction of the volume of the hemispherical shell below the height of the inversion layer (h). In the second case the integration is terminated at the cloud's radius. Both methods may be combined for clouds

with heights that are more limited than their radii.

A description and program listing for this model is given in Appendix C. Table 15 contains an example of a typical program listing. The results of this program are given and discussed in the next chapter.

TABLE 15

RESULTS_OF_THE_CLOUD_SOURCE_MODEL

Typical Small Wood Frame House in infinite cloud. 8 August 84

Integration to 12 MFPs in air.
Equivalent radius of structure = 5.300 meters
Mass thickness of walls = 10.000 gr/cm**2
Maximum cloud height = ************ meters
Maximum cloud radius = ************ meters

E(KeV)	R/hr/Ci*m3 Unprotected	R/hr/Ci*m3 Protected	R/hr/Ci*m3 from int.	DRF	R/R(RSS)	Exclusion Factor
RSS-CLOUD	540.6	372.7	8.922	.6902	1.000	.9766
1.12 HR.	814.2	573.6	13.64	.7045	1.021	.9768
TMI-CLOUD	106.5	57.13	1.052	.5363	.7771	.9686
15000.0	.1277E+05	.1062E+05	120.4	.8312	1.204	.9888
10000.0	8908.	7393.	88.19	.8299	1.202	.9882
8000.0	7144.	5906.	73.96	.8267	1.198	.9876
6000.0	5438.	4455.	59.86	.8192	1.187	.9867
5000.0	4571.	3712.	52.92	.8120	1.177	.9859
4000.0	3687.	2959.	45.27	.8026	1.163	.9849
3000.0	2829.	2225.	37.45	.7864	1.139	.9834
2000.0	1959.	1485.	28.56	.7580	1.098	.9811
1500.0	1512.	1112.	23.31	.7352	1.065	.9795
1332.0	1326.	963.5	21.24	.7266	1.053	.9784
1173.0	1153.	826.2	19.24	.7163	1.038	.9772
1000.0	969.4	680.3	16.98	.7017	1.017	.9756
800.0	770.1	526.1	14.12	.6831	.9897	.9739
662.0	639.4	426.4	11.85	.6670	.9663	.9730
600.0	581.2	382.2	10.81	.6575	.9527	.9725
500.0	471.8	302.1	9.020	.6404	.9278	.9710
400.0	371.9	229.3	7.167	.6164	.8931	.9697
300.0	270.8	156.9	5.205	.5794	.8395	.9679
200.0	187.8	96.41	3.241	.5134	.7439	.9675
150.0	135.1	60.25	2.235	.4461	.6464	.9642
100.0	91.79	29.56	1.426	.3220	.4665	.9540
80.0	75.20	17.34	1.242	.2305	.3340	.9332
60.0	57.77	5.993	1.245	.1037	.1503	.8280
50.0	47.70	1.967	1.393	.4125E-01	.5976E-01	.5855
40.0	36.79	.1851	1.794	.5031E-02	.7289E-02	.9353E-01
30.0	26.43	.4120E-03	2.817	.1559E-04	.2259E-04	.1462E-03
20.0	17.28	.1386E-13	5.436	.8022E-15	.1162E-14	.2549E-14
15.0	13.24	.0000	7.899	.0000	.0000	.0000

2.9 Sources Interior to a Structure

When radioactive materials infiltrate into a structure, they contribute to the exposure received by someone inside the structure. If a passing radioactive cloud deposited particulate material, then there could be two sources interior to a structure: the particulate material that is deposited on the floor of the structure and an interior cloud of gaseous material.

Infiltration is the uncontrolled flow of air through a building as opposed to ventilation which is controlled flow (that is, it can be shut off). For a typical building, infiltration causes from 0.5 to 2. air changes per hour [59]. Infiltration is proportional to the indoor-outdoor temperature difference and windspeed as well as being a function of building construction and condition [59,60].

Therefore, the rate of increase of radioactive gases inside a building is a function of several parameters in addition of the outside concentration. However, unless radioactive decay is rapid, the inside concentration will be essentially equal to the outside concentration in a manner of minutes to at most a few hours.

The infiltration of particulate matter must also be considered. It has been shown that the amount of particulate matter in a building is roughly the same as outside the building [61]. However that work did not

determine how much of the particulate matter came from the outdoor environment. The amount coming from the outside may be very small. It was shown by measurements taken after the 1957 Windscale incident that "the deposition within a building of iodine . . . from a cloud passing around it is generally only 1 or 2 percent of the deposition on the surrounding ground" [62].

The remainder of this section deals with the exposure received from sources inside a building that are of the same concentration as outside. True exposure rates can be found from these data by calculating the actual interior concentrations from infiltration data.

2.9.1 Interior Fallout

The Fallout model also calculates the exposure received from a fallout source interior to a structure. It assumes that the concentration of deposited material is the same as that exterior to the structure. The program allows no shielding for the interior source. The exposure is calculated using the same routine as for the infinite unshielded smooth plane source that is used as the standard for calculating DRFs. The only difference is that the source is limited to the interior radius of the structure. Figure 13 gives the ratio of the exposure received from interior fallout to the sum of the exposure from both interior and exterior fallout, assuming that the concentrations are the same for both. When this ratio is equal to 1.0, all the exposure is from the interior fallout. When it is equal to 0., all the exposure is from external sources.

As shown in Figure 13, if interior fallout is of the same order of magnitude as exterior fallout, it is always important. Below approximately 100 KeV, interior fallout can account for nearly all the exposure.

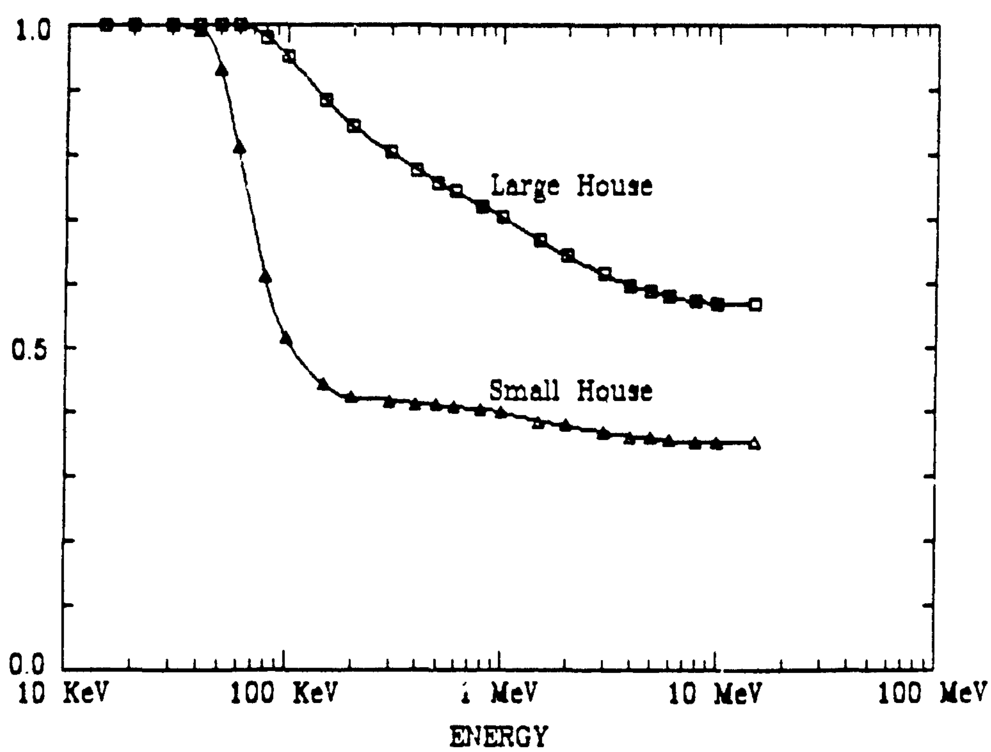

FIGURE 13 Relative Importance of Interior Fallout vs. Source Energy

2.9.2 Interior Cloud

The Cloud model also calculates the exposure received from a cloud source interior to a structure. It also assumes that the concentration in the interior cloud is the same as that of the exterior cloud. The interior cloud is also used to calculate the "exclusion factor" which is useful in determining the importance of infiltration to the total dose received. The exclusion factor is defined as the ratio of the exposure from the exterior cloud to the sum of the exposures from the interior and exterior clouds. An exclusion factor of 1 means the interior cloud contributes nothing to the total exposure. A very small exclusion factor means nearly all the exposure comes from the internal source. Figure 14 shows the value of one minus the exclusion factor as the source energy varies. One minus the exclusion factor is the ratio of the exposure from the interior cloud to the total exposure.

As the energy of the source photons decrease so does their mfp. Thus, at low energies the interior source is very important, but at higher energies it is always insignificant as shown in Figure 14.

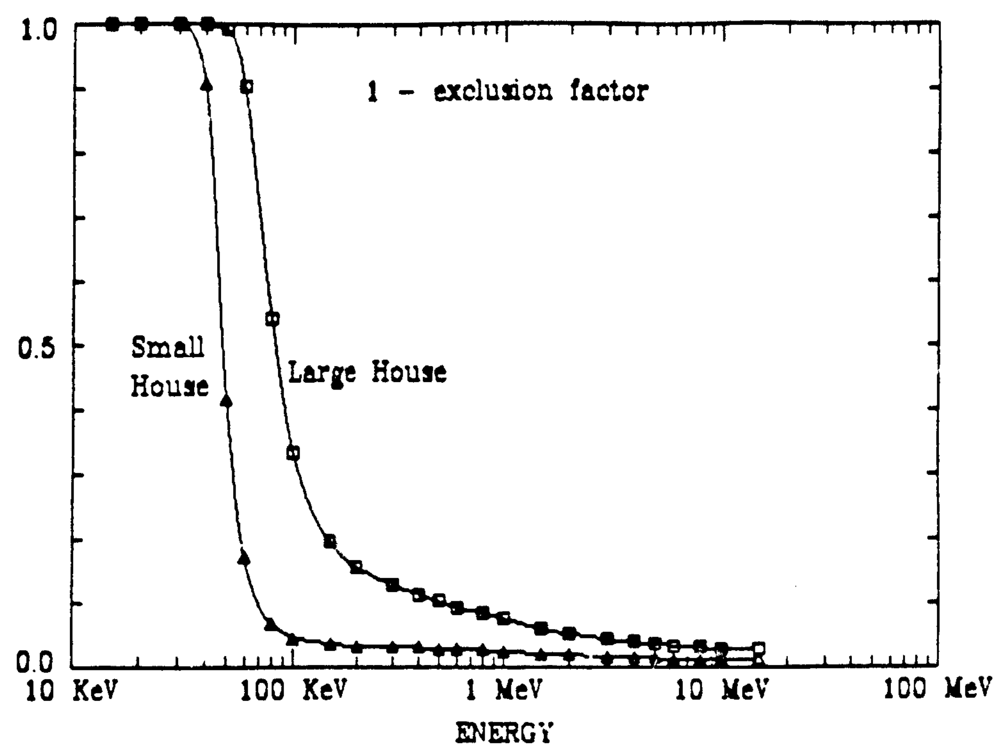

FIGURE 14 Relative Importance of Exposure from Interior Cloud Sources vs. Energy.

CHAPTER III

RESULTS

3.1 Introduction

The results that follow have been obtained from the programs that are documented in the Appendixes. They are not the only results that can be obtained. The programs are designed to allow a very wide range of input data. The Fallout and Cloud programs are intended to provide DRFs that can be used as ratios to translate known DRFs to new spectra. If a particular structure had a known DRF for the 1-hr. bomb spectra but, for example the DRF was needed for the TMI spectra; similar structure dimensions should be used as input to the programs. The results would include a 1-hr. bomb spectra and a TMI spectra value. The ratio of these two values should be multiplied by the known value to obtain the required DRF for the structure. However, the results found by the programs are very close, often within 1 percent, to the values found for similar structures in the literature. Therefore the results reported here do not include any such translations. DRFs for other spectra can be obtained from the values for specific energies that are

given as part of the program outputs.

In order to compare results for specific structure types, the following structures are defined from values found in the literature [55]. A "small wood house" has a roof and walls of 10 gr/cm^2 mass thickness and a 5 m. equivalent radius and height (about 1000 sq. ft. of floor area). A "large brick house" has 22 gr/cm^2 walls and a 22 gr/cm^2 roof with a 10 m. equivalent radius (about 3000 sq. ft.). A "Small Block House" is 1 meter in radius, 2 meters high and has 1 foot thick concrete walls. The "thin walled house" has walls of 3.4 gr/cm^2 mass thickness. The "thin walled house" is included to allow comparison with values found in the literature [56,57,58] as discussed in Section 2.8.

The ground roughness surface types use the parameter values reported in Table 13.

3.2 Effect of Ground Roughness

Ground roughness factors are used in the current shielding literature as multipliers for DRFs found for structures alone. However, because the ground roughness changes the spectra of the fallout radiation source, and further because the change in the spectra is energy dependant, the ground roughness factor cannot be separated from the total DRF, except for specific spectra. In order to see the energy dependant nature of the ground roughness factors, the DRFs obtained for a structure surrounded by a particular ground type can be divided by the DRFs obtained for the same structure surrounded by the hypothetical infinite smooth plane. Figure 15 shows the effect of Ground Roughness on the exposure inside a small wood framed house. The figure represents the ratio of the DRF found for the house, with the ground taken into account, to the DRF found for the same house over a smooth plane. Thus the plotted result is the DRF associated with the ground effect in the way it is usually used, that is to multiply the DRF found for the structure itself. Figure 16 does the same for a large brick house.

The Lawn, Gravel, and Plowed Field would give DRFs of 0.80, 0.70 and 0.60 respectively if found for an infinite plane with no structure present. With a structure present, the DRFs are smaller (the effect greater) for energies above

30 KeV for a small wood house and 50 KeV for a large brick house. The DRFs are smaller because the structure walls provide greater attenuation for the photons that have lost energy in interactions with the ground. Below the 30 and 50 KeV energies, the mfps of the gammas are so short that the ground plays almost no role in the shielding.

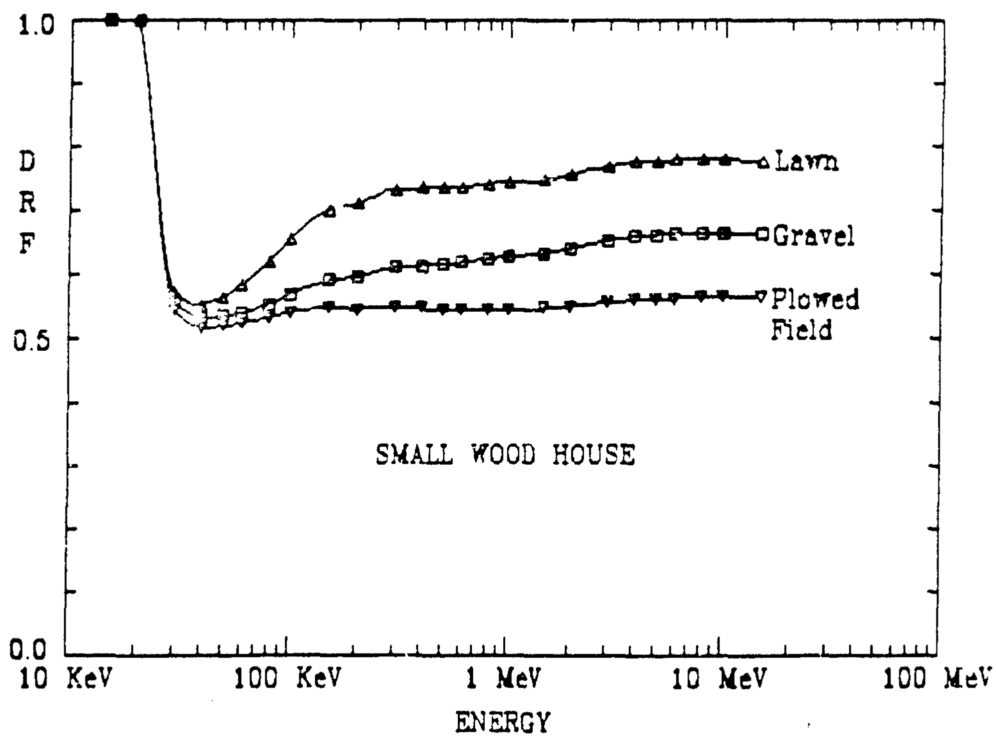

FIGURE 15 <u>The Effective Energy Dependent Ground Roughness Factor for a Small Wood House.</u>

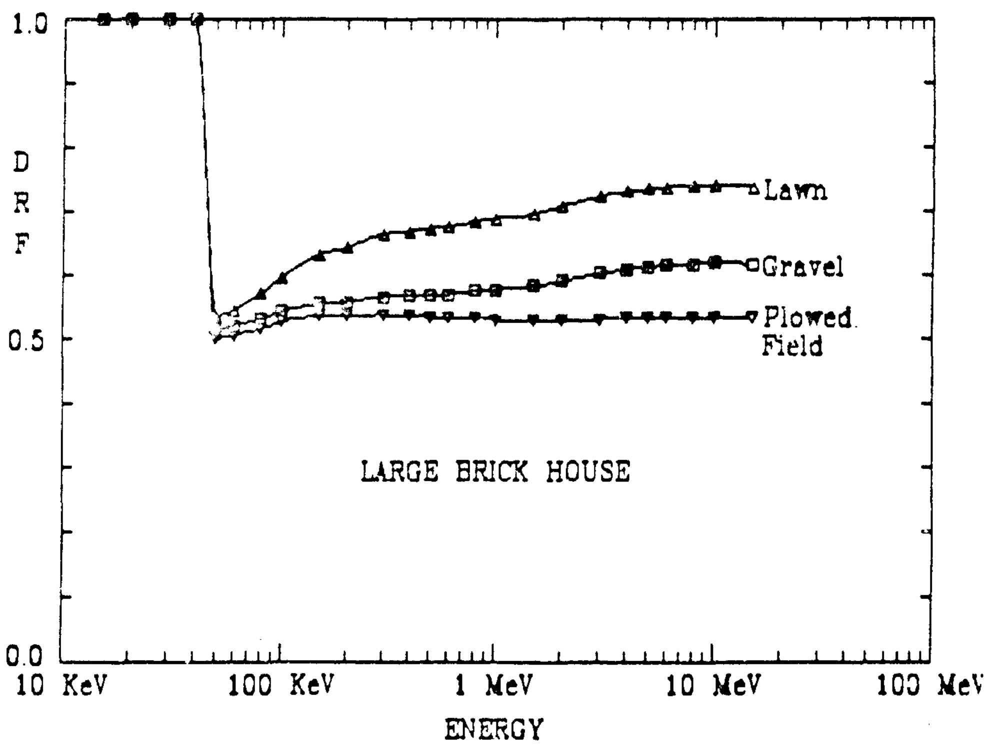

FIGURE 16 The Effective Energy Dependent Ground Roughness Factor for a Large Brick House.

3.3 Effect of Building Size on Fallout Exposure

Figure 17 shows the energy dependent DRFs for "small wood houses", "large brick houses", and "small block houses." For a small wood house on a lawn, the DRF is nearly constant for energies greater than 300 KeV. Below 40 KeV, the DRFs (and therefore the doses) are near zero. With the large brick house and the "block" house, the DRFs increase nearly linearly with the logarithm of energy over a wide energy range.

Figures 18 and 19 demonstrate the effect of increasing structure dimensions. Figure 18 shows the effect of increasing the building size (effective radius) for a wood structure. A doubling of the building radius reduces the DRFs by about 22% uniformly for all energies. This is because increasing the building size effectively removes part of the source. Figure 19 shows the effect of increasing the wall thickness for a small house. Note the sharp drop in the DRFs at lower energies and with increasing wall thickness. The effect of increasing the wall thickness is much more energy dependent than increasing building size.

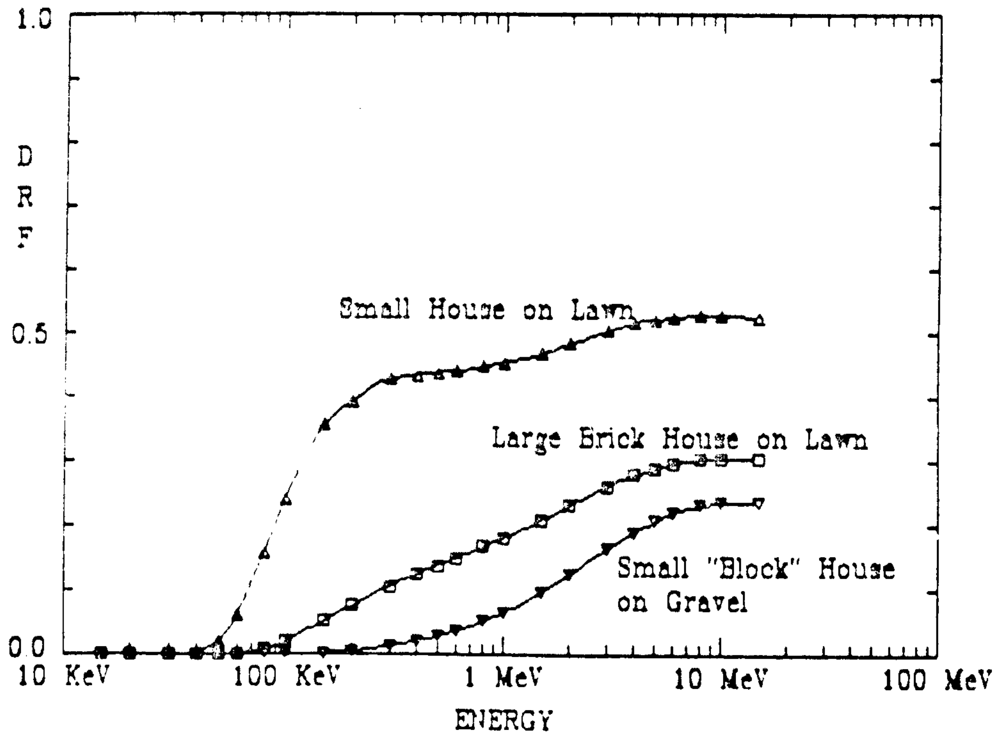

FIGURE 17 DRF vs. Energy for Buildings Exposed to Fallout

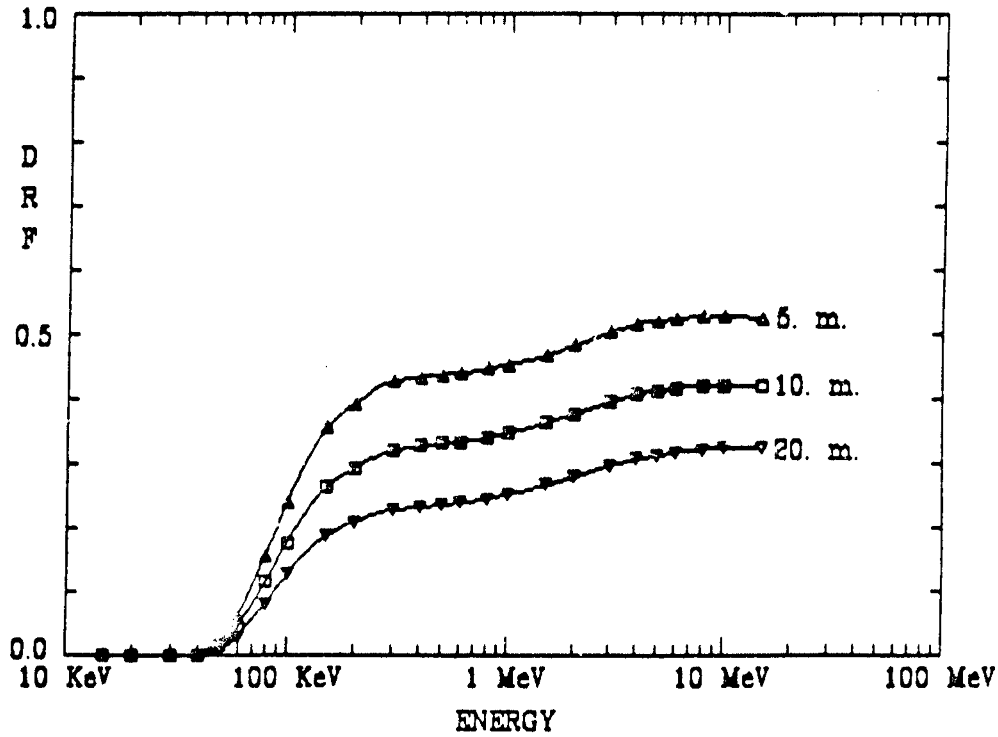

FIGURE 18 DRF vs. Energy for Increasing Building Size for Fallout Sources (Wood House)

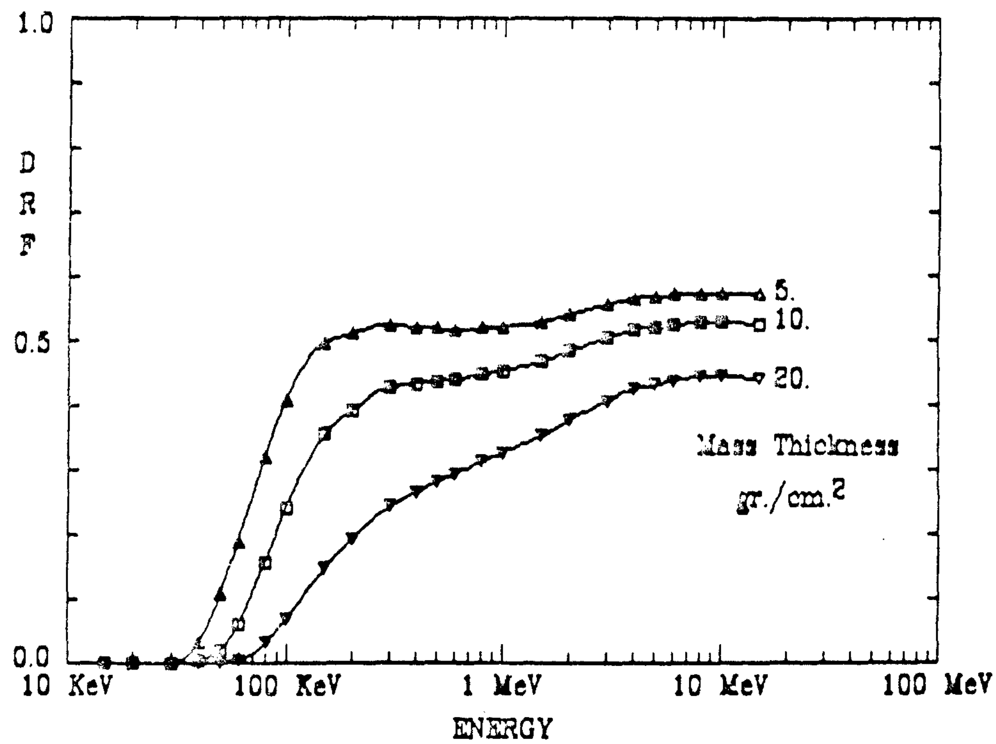

FIGURE 19 DRF vs. Energy for Increasing Wall Mass Thickness for Fallout Sources (5.0 meter effective radius)

3.4 Effects of Cloud Sources

The effective DRF vs. Energy curve for four different structures is given in Figure 20. The results of increasing the building size are pronounced. Figure 21 shows the effect of increasing wall thickness on the DRF for an infinite cloud source. The effect is nearly the same as seen in Figure 20. Figure 22 shows that effect of increasing the building effective radius for a structure is very small. This is due to the nature of a spherical source, which has no "1/R" dependence.

Figures 23 and 24 demonstrate the effect of limiting the cloud size. Limited cloud size has very little effect on the DRFs. However, while the DRFs are not effected, the doses are greatly effected as shown in Figure 25. The kernel plotted in Figure 25 includes the exposure rate term, which is energy dependent. The effect of limiting the cloud size is to reduce the number of higher energy gamma photons that can reach the structure. Both the protected and unprotected exposures are limited in Figures 23 and 24.

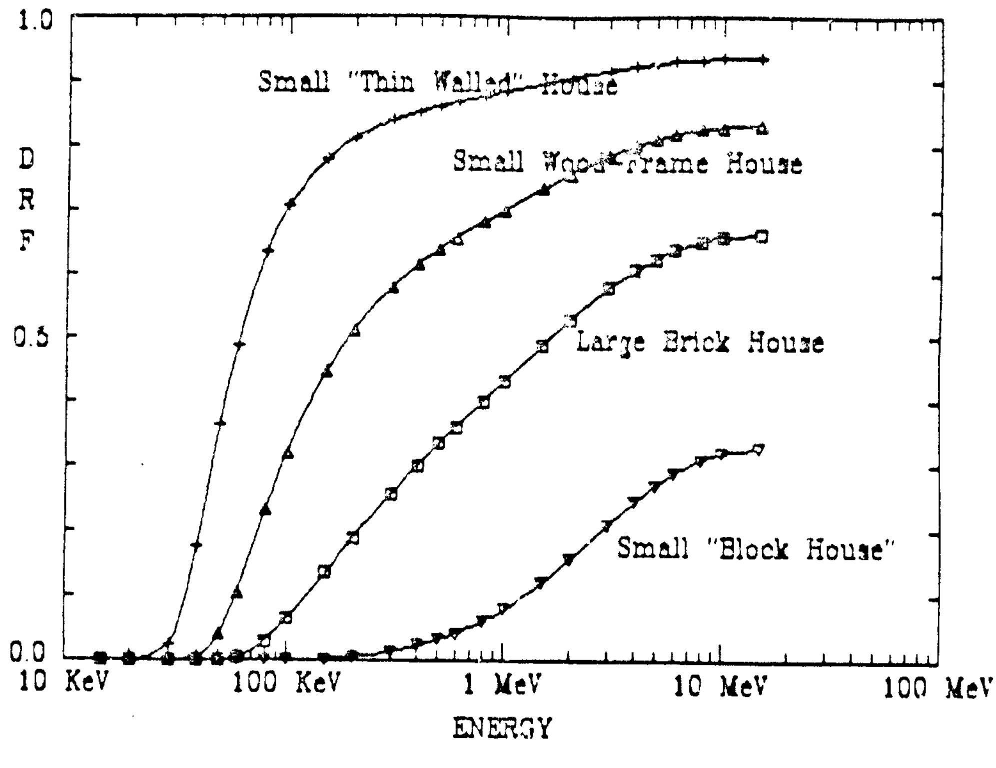

FIGURE 20 DRF vs. Energy for a Cloud Source

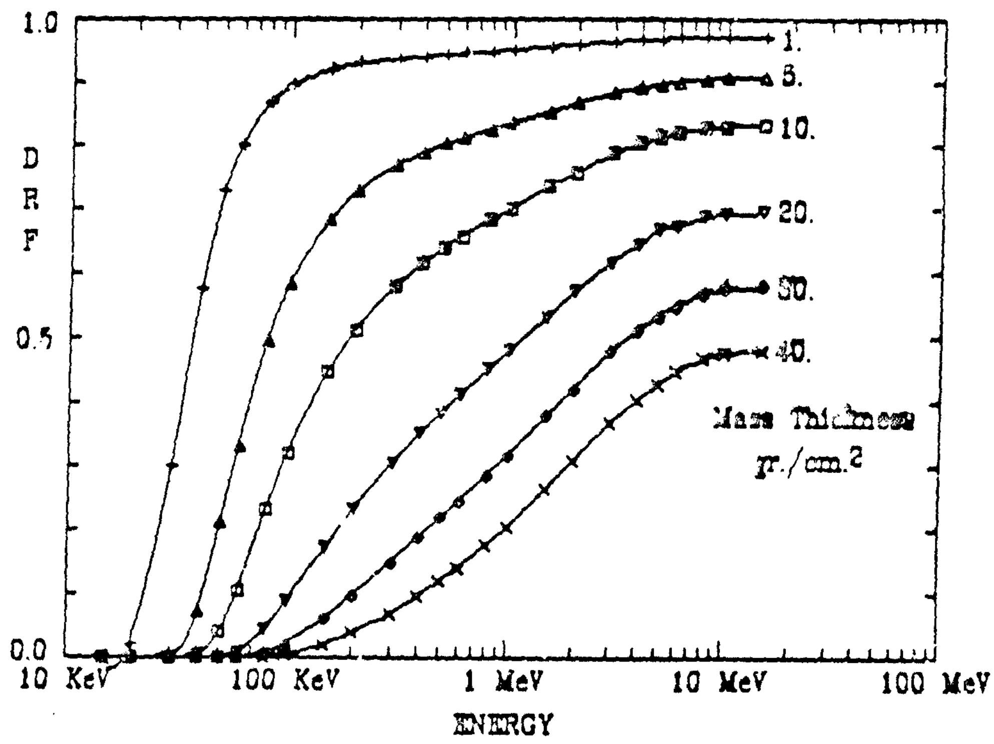

FIGURE 21 DRF vs. Increasing Wall Mass Thickness for a Cloud Source (5.0 Meter Effective Radius)

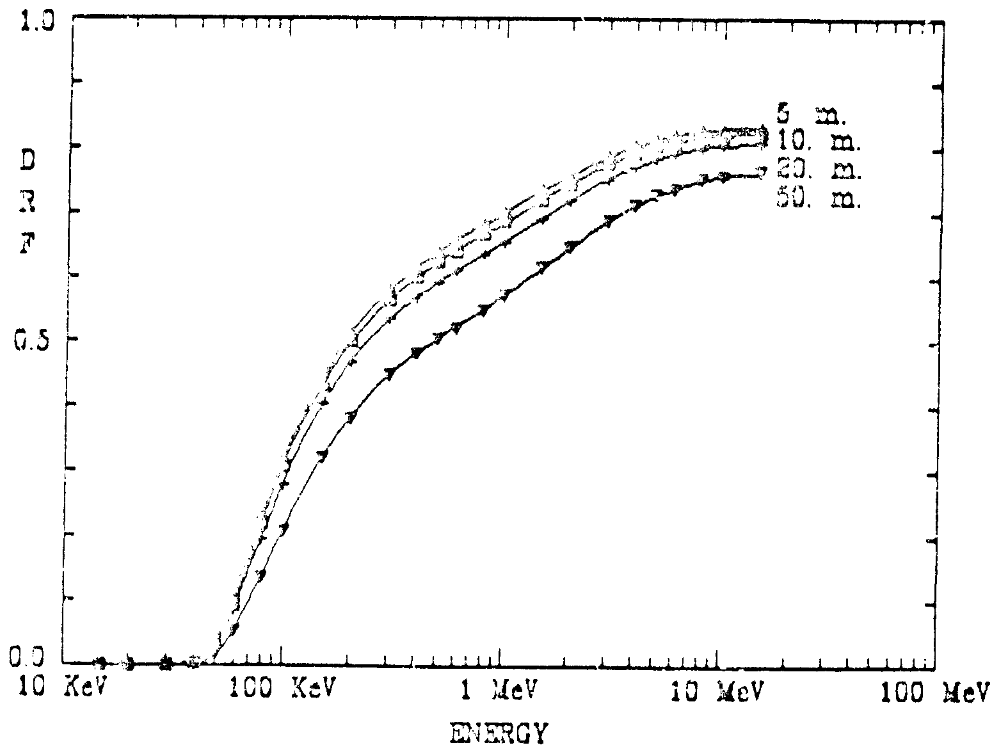

FIGURE 22 DRF vs. Effective Radius for a Wood Structure for a Cloud Source

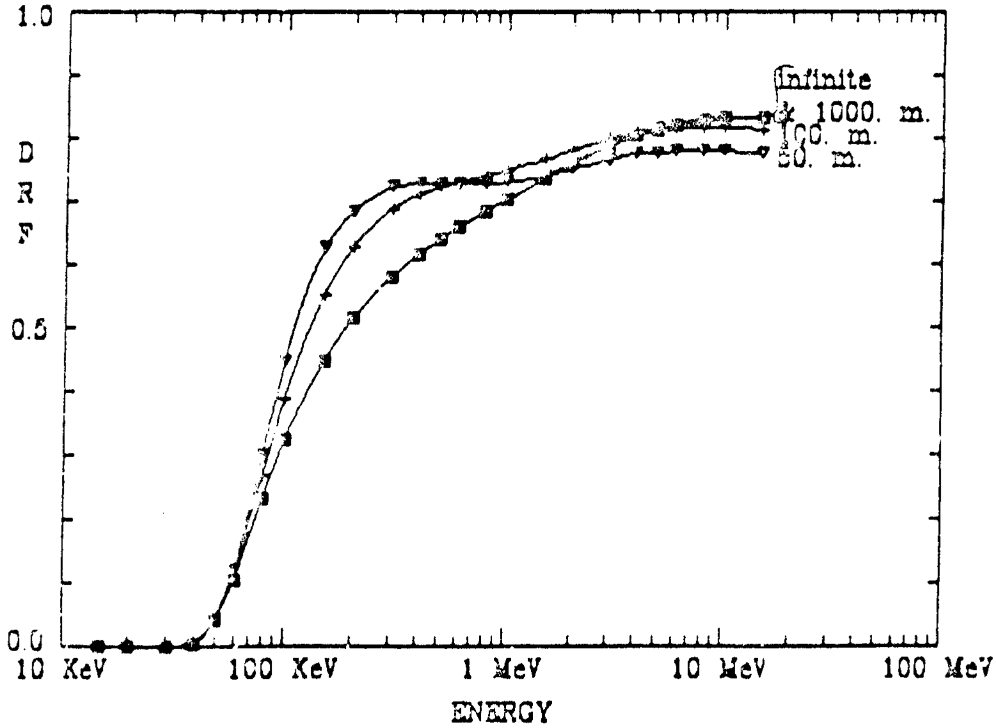

FIGURE 23 DRF vs. Energy for a Cloud Source of Limited Radius (Small Wood House)

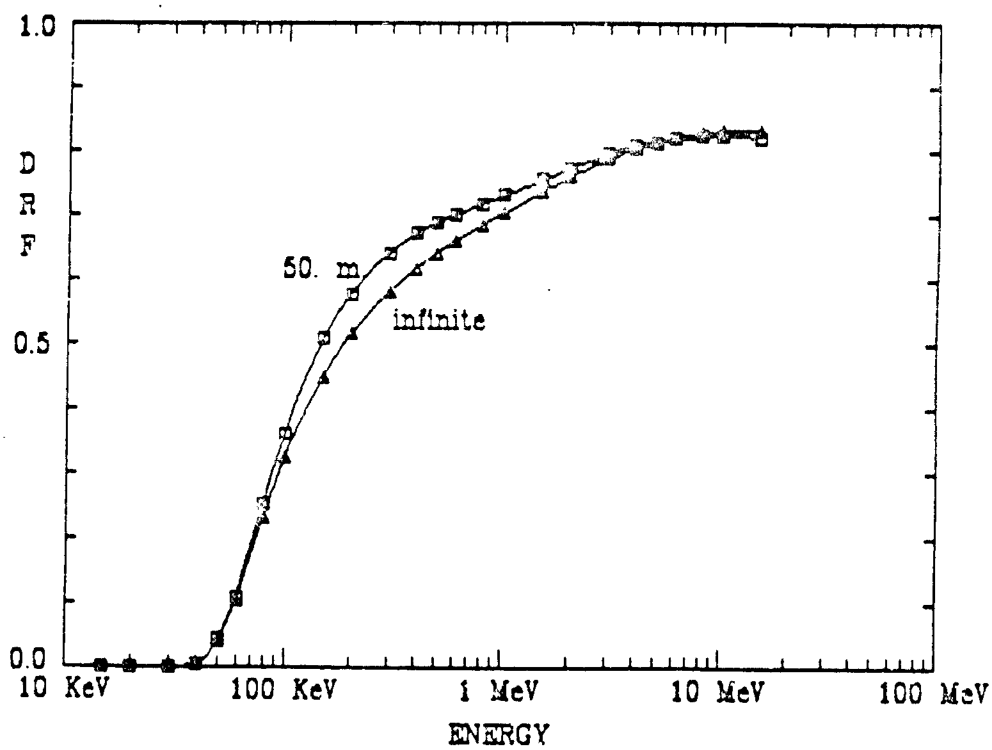

FIGURE 24 DRF vs. Energy for a Cloud Source of Limited Height (Small Wood House)

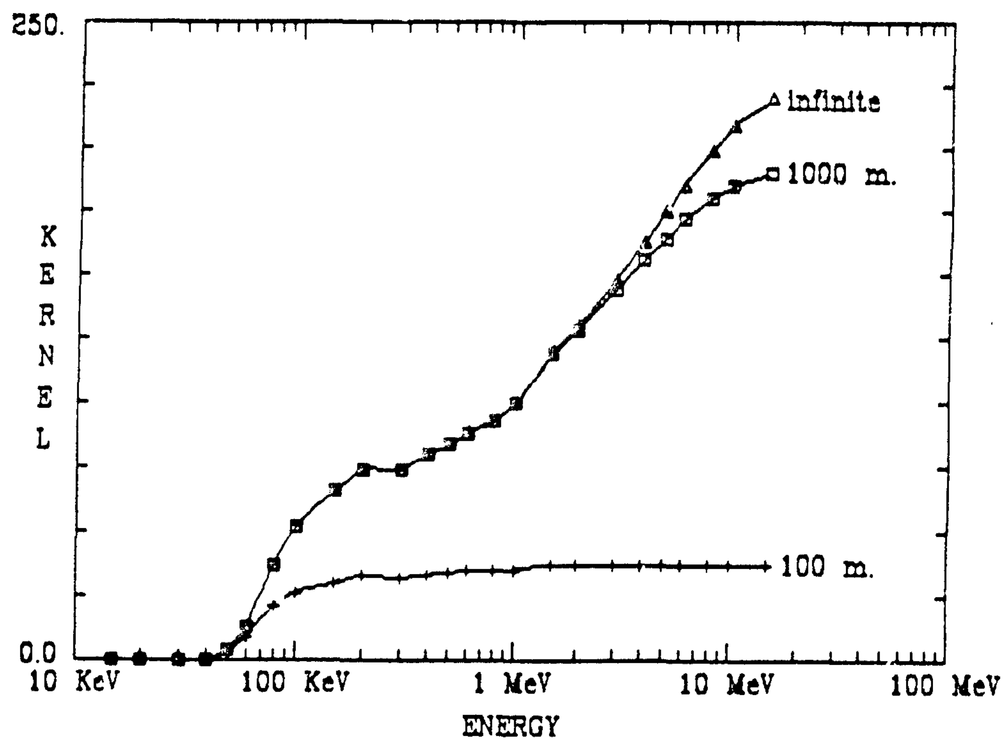

FIGURE 25 KERNEL vs. Energy for a Cloud Source of Limited Radius (Small Wood House)

CHAPTER IV

CONCLUSIONS

The contributions of this dissertation to the current literature come in three ways: first, in the questions it answers; second, in the models developed; and third, in the results of the models.

The primary result of this work is its answering of the question, "Can the DRFs found for one spectra be used for cases involving other spectra without serious error?"

The Reactor Safety Study assumed a DRF of 0.33 for all photons from all isotopes either from cloud or fallout sources [63]. The results reported here clearly show that this assumption is not strictly in accordance with reality. Other works have used the DRFs found for weapon fallout to predict the outcome of a reactor accident [8,9,10,11]. In all these works, the underlying assumption was that their numbers were "conservative". This work can be used to prove or disprove those assumptions and make the results closer to reality.

Table 16 gives DRFs found for fallout using the model just presented. Table 17 does the same for cloud sources.

TABLE 16

DRFs FOR FALLOUT SPECTRA

Spectra	Structure	DRF
1. Hr Fallout	Small House on Lawn	0.455
PWR-2 (RSS)		0.456
TMI - Fallout		0.432
SL-1 - Fallout		0.433
1. Hr	Large House on Lawn	0.184
PWR-2		0.192
TMI		0.123
SL-1		0.125
1. Hr	Small Block House/gravel	0.074
PWR-2		0.085
TMI		0.021
SL-1		0.022
1. Hr	Small house/ smooth plane	0.611
PWR-2		0.610
TMI		0.588
SL-1		0.589
1. Hr	Large House/ plowed Field	0.144
PWR-2		0.149
TMI		0.102
SL-1		0.103

TABLE 17

DRFs FOR CLOUD SPECTRA

Spectra	Structure	DRF
PWR-2 (cloud)	Small Wood House	0.690
TMI (cloud)		0.536
PWR-2	Large Brick House	0.440
TMI		0.255
PWR-2	Small "Block House"	0.108
TMI		0.036
PWR-2	Small "Thin Walled House"	0.871
TMI		0.808

The decade old question, "Is the DRF for a PWR-2 event approximately equal to that of fallout from an 'atomic bomb'?", is answered - yes! That was a good assumption. This answer may seem a bit surprising until the definition of a PWR-2 event is recalled. A PWR-2 event (see the introduction) involves the sudden release of a significant amount of core material without decay time [16].

The DRFs for accidents that have happened (SL-1 and TMI) are smaller than those of a PWR-2 event. This is especially the case for large buildings with thick walls. This is because most of the radioactive material released consisted of Xe-133 which has a 81 KeV photon that is comparatively easy to attenuate.

It is not a unique observation that large buildings attenuate photons more than small buildings, however the magnitude and energy dependence of the differences is unique. The values given here can influence decisions concerning where to seek shelter and when to evacuate. The values found here can be extended to vehicles also. A vehicle has very little material for shielding (about 2 gr/cm^2) [11] and a very high infiltration rate (about 18 air changes every hour at low speeds) [64]. Therefore, if the public is evacuated while a radioactive cloud is passing, they may receive a much higher dose than if they sought shelter. This work should influence that decision. In a

particular situation, for example, this work would help show that it may be safer to seek shelter in a large office building or factory that is near by than it is to attempt to evacuate on a crowded highway.

There were other important contributions made during the development of this work. First, there is now a simple, easily understood method for accurately combining buildup factors in multi-region problems that works for all reasonable gamma energies. Previous methods were either based upon conservatism rather than accuracy, or had a narrow range of energies for which they were applicable.

Second, there is now a model for determining the shielding effect of ground roughness that is applicable to all spectra. Previous models were only applicable to a particular spectrum.

Third, there is now a model for determining the change in shielding factors with changing source energy for a particular shield. Previously, each new source required the entire shielding problem to be re-solved, now the problem needs to be solved only once -- and the results for all energies can be determined.

The results reported in this work, and the methods presented for extending them to other situations are also very important contributions.

It was not known that the ground roughness factor was essentially energy independant above 200 KeV (see Figures 15 and 16).

It was not known how the DRFs provided by structures for fallout varied with energy -- it was not known, for instance, that above 200 KeV the DRF for a small house is essentially constant, but below 50 KeV it is essontially zero (see Figure 17). It was not known that the DRF for a large house varies somewhat linearly with the logarithm of energy over a large energy range.

It was not reported that the DRF of a structure in a cloud source was essentially independent of the building's size (effective radius). It was not reported that the DRFs for a cloud source were essentially independent of any limitations on the clouds height or radius. That is, the same DRFs can be used during inversions or very close to the point of release, and during all stability conditions (provided the clouds radioactive composition remains uniform) that are used for infinite clouds.

The relative importance of interior fallout and cloud sources as a function of energy was not known. It is now known that for a large house, at energies below about 100 KeV essentially all the dose from fallout could come from dirt that infiltrates into the house, rather than from exterior fallout (see Figure 13). It was not reported that

interior clouds are unimportant in small houses for nearly all energies except below about 70 KeV (see Figure 14).

In summary, a model for the protection provided by structures, such as homes, against releases of airborne radioactive materials, as a function of the gamma energy spectrum of the released material has been developed and evaluated -- that was the objective of this research.

CHAPTER V

RECOMMENDATIONS

This model is but a part of a larger work which should be completed and should include a dispersion model, an evacuation model and an infiltration model (see Figure 1). The data derived from this model should then be used to predict the exposure the public could expect to receive from a release of radioactive material of any kind. This should be done on a real time basis as outlined in the introduction so that informed decisions can be made regarding evacuating or sheltering the public in order to reduce exposure and injury.

A simple method of measuring the effective mass thickness of the walls of existing structures should be developed to allow rapid surveying of populated areas where radioactive releases are most likely to happen.

A Monte-Carlo study should be conducted to determine the exact accuracy and limits of applicability with regard to varying Z number and energy of the method presented here for combining buildup factors in multi-region problems.

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APPENDIX A

GROUND FACTOR PROGRAM DESCRIPTION AND LISTING

The Ground Factor program calculates the value of the trough width w (see Section 2.6.2) that gives a known DRF for a specified spectra. The ratio d/w and the angle must also be specified (see Equations 2.19 and 2.20). The value of w found is required as input to the Fallout program.

When the Ground Factor program is run, it will ask for input data as shown in Figure 26. After asking for a title and date for the output listing, the program asks for a "Radius to the inside of an infinite disk in meters." This value is normally zero, indicating integration over an infinite plane. A value other than zero can be used to study the effect of a central void in the source, such as that caused by a house. The next question asked is "Do you wish to calculate a TERRAIN FACTOR from a known DRF?". Normally the answer should be yes (y). The no (n) option allows a quick listing of the output for a known value of w. Only a "yes" will calculate w. The program can presently find w for values of the DRF found for the Cs-137, Co-60, PWR-2, and 1-Hr bomb fallout spectra. After choosing the

proper spectra, you must input the given DRF, d/w and Ψ. The program then iteratively finds w and gives the resultant DRF's for energies from 15 KeV to 15 MeV and for the PWR-2 and 1-Hr bomb fallout spectra as shown in Table 18. The program refers to w as the "terrain factor" and Ψ as "theta".

The program is written in Microsoft FORTRAN 3.13. This is a version of FORTRAN 77. There are no non-standard FORTRAN commands in the program. The program was run on a Texas Instruments Professional Computer (PC) which uses an 8088 processor and an 8087 co-processor. The program was run under the MS-DOS 2.11 operating system. However, it should run on any computer capable of using FORTRAN 77. The program takes approximately 30 minutes running time. Caution, the program is written is FORTRAN, the input requires decimal points.

```
R GFACTOR
INPUT TITLE/DATE OF OUTPUT
Test for Demonstration. 16 Sept 1984
INPUT RADIUS TO INSIDE OF INF DISK IN METERS 5.
Do you wish to calculate a TERRAIN FACTOR from a known DRF? y or n y
Choose the spectrum from which your DRF was obtained:
   Cs-137 (input 1)
   Co-60 (input 2)
   Reactor Safety Study (input 3)
   1.12 Hr. Bomb deposition (input 4)
   Other -limit 20 groups (input 5) ? 4
Input given DRF .8
Input given D over W .959
Input given theta 45.
```

FIGURE 26 Typical Computer CRT Display During Initiation of Ground Factor Program.

TABLE 18

TYPICAL OUTPUT OF THE GROUND FACTOR PROGRAM

Lawn. 16 Sept. 1984

Integration to 12 MFPs in air.
Detector is 1 meter above smooth plane
Radius to inside of disk in infinite plane = .000 meters
Terrain factor = 2.3698
Terrain Factor calculated from 1.12 Hr. fallout spectrum. Given = .0000
D over W (ratio of flat surface to groove) = .9590
Theta (ground sawtooth angle) = 45.0000 degrees

E(KeV)	KERNAL	R/hr/Ci**2	MFP1	D2 (meters)	TERRAIN KERNAL	DRF
15000.	2.8616	135.44	.00000	5127.5	2.3532	.82234
10000.	2.8478	100.69	.00000	4549.4	2.3493	.82497
8000.0	2.8336	84.189	.00000	4161.8	2.3434	.82597
6000.0	2.8157	67.697	.00000	3662.8	2.3244	.82550
5000.0	2.7954	59.487	.00000	3374.8	2.3076	.82460
4000.0	2.7828	50.588	.00000	3013.2	2.2932	.82405
3000.0	2.7683	41.599	.00000	2592.4	2.2676	.81911
2000.0	2.7659	31.628	.00000	2085.6	2.2403	.81016
1500.0	2.7604	25.912	.00000	1791.6	2.2329	.80219
1332.0	2.7586	23.416	.00000	1687.1	2.2163	.80341
1173.0	2.7326	21.012	.00000	1582.0	2.1976	.80424
1000.0	2.7006	18.344	.00000	1459.2	2.1728	.80457
800.00	2.6800	15.152	.00000	1312.7	2.1578	.80447
662.00	2.6909	12.750	.00000	1205.2	2.1614	.80333
600.00	2.6971	11.664	.00000	1152.9	2.1632	.80283
500.00	2.6663	9.6438	.00000	1066.8	2.1400	.80545
400.00	2.6513	7.6443	.00000	972.82	2.1426	.80817
300.00	2.6210	5.5338	.00000	867.36	2.1317	.81774
200.00	2.8153	3.6876	.00000	754.53	2.2382	.79489
150.00	2.8231	2.5867	.00000	682.41	2.2343	.79142
100.00	3.1923	1.8195	.00000	602.65	2.3597	.74138
80.000	3.4966	1.6609	.00000	555.73	2.4460	.69953
60.000	3.5988	1.6092	.00000	493.66	2.3624	.65644
50.000	3.2844	1.6291	.00000	446.19	2.0916	.63682
40.000	2.6604	1.7395	.00000	374.22	1.6704	.62787
30.000	1.9130	2.0753	.00000	265.92	1.2000	.62729
20.000	1.1020	2.7538	.00000	123.41	.72861	.66071
15.000	.67032	3.1446	.00000	59.876	.47284	.70540
RSS	2.8000	14.639	**********	**********	2.1661	.77360
1.12 Hr.	2.6911	14.827	**********	**********	2.1530	.80003

The MAIN program directs the input and output of the program data. Subroutine SIMPS carries out the integrations by using Simpson's rule. The number of increments is automatically increased until the desired accuracy is obtained. Subroutine PROTECT speeds the integration of the disk source by dividing the disk into rings which converge to integrals faster. Function DISK finds the kernel for the hypothetical infinite smooth disk source. Function GROUND calculates the kernel for the fallout using the methods developed in Section 2.6.2.

Function AMU finds the mass attenuation coeficient for air. Function BUF finds the buildup factor for air. Function MUCONC finds the mass attenuation coeficient for the ground. Function BCONC finds the buildup factor for the ground. Function ROENTG finds the factor for converting flux to exposure.

The listing of the Ground Factor program follows.

```
      PROGRAM GRDFCT
C
      CHARACTER CTITLE*116,YORN*1
      INTEGER IN, OUT
      REAL E(28), MU, MFP1, LININT
      REAL EGROUP(20,4), FRACT(20,4)
C     EXTERNAL  DISK, GROUND
      COMMON /ENERGY/ EKEV, MU, BU, W,THETA,DOVERW
      COMMON /INOUT/ IN, OUT
      COMMON /OLDJ/ EOLD, JOLD
      COMMON /OLDJ2/ EOLD2, JOLD2
      COMMON /FLAG/ RMAX
      COMMON/KERNAL/TOTKRN,TOTDOS,TDIRT,MFP1,D2,R1
C^^^^^^ NOTE RADII ARE IN METERS, ENERGIES IN KeV, DENSITIES IN gr/cm*2
C
      DATA E/15.,20.,30.,40.,50.,60.,80.,100.,150.,200.,300.,
     1 400.,500.,600.,662.,800.,1000.,1173.,1332.,1500.,
     2 2000.,3000.,4000.,5000.,6000.,8000.,10000.,15000./
      DATA EGROUP /661.640,19*0.,1173.2,1332.5,18*0.,
     1 50.,300.,750.,1500.,2500.,15*0.,
     2 25.,75.,150.,250.,350.,500.,700.,900.,1165.,
     3 1500.,1830.,2250.,2750.,3500.,4500.,5*0./
      DATA FRACT /1.,19*0.,
     1 1.,1.,18*0.,
     2 .1696,.2431,.2760,.2183,.0930,15*0.,
     3 .0271,.0137,.0737,.0476,.0929,.1373,.1717,.1627,
     4 .0889,.0957,.0299,.0397,.0148,.0042,.0001,5*0./
C******* LINEAR INTERPOLATION FUNCTION
      LININT(X,X1,X2,Y1,Y2) = (Y2-Y1)*(X-X1)/(X2-X1) + Y1
C^^^^^^^^ATTEMPT TO CONTROL PRINTER FROM FORTRAN TO COMPRESS PRINT
      OPEN (1,FILE='LPT1',STATUS='NEW',ACCESS='DIRECT'
     1 ,FORM='UNFORMATTED',RECL=1)
      WRITE (1)27,15
      CLOSE (1)
      OPEN(1,FILE='LPT1')
C
C****************************************************************
C***************INPUT TITLE FOR EACH LISTING**********************
 807  FORMAT(1H0,32X,'SEMI-INFINITE DISK SOURCE IN AIR',
     1 ' WITH NEW GROUND FACTOR USING Tave. 13 JULY 1984')
C****************************************************************
      OPEN(1,FILE='LPT1')
C
      OUT = 1
      EOLD = 0.0
      EOLD2 = 0.0
      IN = 0
      NSPEC = 0
C%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
      WRITE(*,290)
 290  FORMAT(1X,'INPUT TITLE/DATE OF OUTPUT')
```

```
      READ(*,291)CTITLE
 291  FORMAT(A116)
 292  FORMAT(1H0,15X,A116)
C------------------------------
      WRITE(OUT,807)
      WRITE(OUT,292)CTITLE
      WRITE(OUT,808)
      WRITE(OUT,804)
 300  WRITE(*,301)
 301  FORMAT(1X,'INPUT RADIUS TO INSIDE OF INF DISK IN METERS  ',\)
 302  READ (*,303) RR1
 303  FORMAT(F13.6)
C**********************************************************
C*****ROUTINE FOR FINDING TERRAIN FROM KNOWN SPECTRA
C*********************************************************
 729  WRITE(*,730)
 730  FORMAT(1X,'Do you wish to calculate a TERRAIN FACTOR ',
     1 'from a known DRF? (y or n)',\)
      READ(*,731)YORN
 731  FORMAT(A1)
            IF(YORN.EQ.'Y'.OR.YORN.EQ.'y') THEN
             GOTO 750
            ELSEIF(YORN.EQ.'N'.OR.YORN.EQ.'n') THEN
             GOTO 722
            ELSE
             GOTO 729
            ENDIF
 750  WRITE(*,732)
 732  FORMAT(1X,'Choose the spectrum from which your DRF was optained:'
     1 ,/,'     Cs-137 [input 1]',/,'     Co-60 [input 2]',/,
     2 '     Reactor Safety Study [input 3]',/,
     3 '     1.12 Hr. Bomb deposition [input 4]',/,
     4 '     Other -limit 20 groups [input 5]  ? ',\)
      READ(*,733)NSPEC
 733  FORMAT(I1)
            IF(NSPEC.GE.1.AND.NSPEC.LE.5) GOTO 734
            GOTO 750
 734  IF(NSPEC.LE.4) GOTO 760
      WRITE(*,799)
 799  FORMAT(1X,'THIS FEATURE IS NOT IMPLEMENTED YET - TRY AGAIN')
      GOTO 750
 760  CONTINUE
 735  WRITE(*,736)
 736  FORMAT(1X,'Input given DRF  ',\)
      READ(*,303)GIVEN
 722  WRITE(*,766)
 766  FORMAT(1X,'Input given D over W  ',\)
      READ(*,303)DOVERW
      WRITE(*,767)
 767  FORMAT(1X,'Input given theta ',\)
      READ(*,303)THETA
```

```
      IF(YORN.EQ.'N'.OR.YORN.EQ.'n') GOTO 721
      R1 = 0.
      N3 = 0
      GUESS1 = 1.
      W1 = 0.
      W2 = 2.0
      W3 = W2
 700  CONTINUE
      SUMDEN = 0.
      SUMNOM = 0.
      W = W3
      WRITE(*,777)W,GUESS2
 777  FORMAT(1H ,/,' GUESS= ',G14.7,
     2 ' PROTECTION FACTOR = ',G14.7)
        DO 701 IEKEV = 1,20
       EKEV = EGROUP(IEKEV,NSPEC)
      FRCT = FRACT(IEKEV,NSPEC)
      RMAX = 1.E8
C-----RESET RMAX IN FLAG EACH TIME ENERGY IS CHANGED
      IF(FRCT.EQ.0) GOTO 701
      WRITE(*,806) EKEV
C-----LET YOU KNOW PROGRAM IS RUNNING
      CALL PROTECT(DRF)
       WRITE(*,702) DRF
      SUMDEN = SUMDEN + TOTKRN * FRCT
      SUMNOM = SUMNOM + TDIRT * FRCT
 702  FORMAT(1X,'PF = ',G14.7,\)
 701  CONTINUE
      IF(N3.EQ.0) THEN
        GUESS2 = SUMNOM/SUMDEN
        N3 = 1
        W3 = LININT(GIVEN,GUESS1,GUESS2,W1,W2)
        GOTO 700
      ELSE
        GUESS3 = SUMNOM/SUMDEN
      ENDIF
      IF(ABS(GUESS3-GIVEN).LT.1.E-4) GOTO 720
      GUESS1 = GUESS2
      GUESS2 = GUESS3
      W1 = W2
      W2 = W3
      W3 = LININT(GIVEN,GUESS1,GUESS2,W1,W2)
      GOTO 700
 720  CONTINUE
      WRITE(*,777)W,GUESS3
 721  CONTINUE
C***********************************************************************
      IF(YORN.EQ.'Y'.OR.YORN.EQ.'y') GOTO 740
      WRITE(*,304)
      READ(*,303) W
 304  FORMAT(1X,'INPUT TERRAIN FACTOR  ',\)
```

```
 740  CONTINUE
      R1 = RR1
      WRITE(OUT,809)R1
      WRITE(OUT,820)W
      IF(NSPEC.EQ.0) WRITE(OUT,791)
      IF(NSPEC.EQ.1) WRITE(OUT,792) GIVEN
      IF(NSPEC.EQ.2) WRITE(OUT,793) GIVEN
      IF(NSPEC.EQ.3) WRITE(OUT,794) GIVEN
      IF(NSPEC.EQ.4) WRITE(OUT,795) GIVEN
      IF(NSPEC.EQ.5) WRITE(OUT,796)
      WRITE(OUT,797) DOVERW
      WRITE(OUT,798) THETA
 791  FORMAT(16X,'Terrain Factor given as input')
 792  FORMAT(16X,'Terrain Factor calculated from Cs-137 spectrum.',
     1 '  Given = ',F10.4)
 793  FORMAT(16X,'Terrain Factor calculated from Co-60 spectrum.',
     1 '  Given = ',F10.4)
 794  FORMAT(16X,'Terrain Factor calculated from RSS spectrum.',
     1 '  Given = ',F10.4)
 795  FORMAT(16X,'Terrain Factor calculated from 1.12 Hr.',
     1 ' fallout spectrum.  Given = ',F10.4)
 796  FORMAT(16X,'Terrain Factor calculated from given spectrum')
 798  FORMAT(16X,'Theta (ground sawtooth angle) = ',F10.4,' degrees')
 797  FORMAT(16X,'D over W (ratio of flat surface to groove) = ',
     1 F10.4)
 411  CONTINUE
      WRITE(OUT,803)
C%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
C%%%%% ROUTINE FOR GENERATING ENERGY/DRF TABLE
C%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
          DO 801 IEKEV = 28,1,-1
        EKEV = E(IEKEV)
      WRITE(*,806) EKEV
 806  FORMAT(1X,'E(KeV) = ',G10.5,\)
      RMAX = 1.E8
C-----RESET RMAX IN FLAG EACH TIME ENERGY IS CHANGED
C-----LET YOU KNOW PROGRAM IS RUNNING
      CALL PROTECT(DRF)
       WRITE(OUT,802) EKEV,TOTKRN,TOTDOS,MFP1,D2,
     1  TDIRT,DRF
 801        CONTINUE
 800  CONTINUE
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
C@@@@@ ROUTINE TO FIND DRFS FOR SPECTRA
      DO 500 NSPEC = 3,4
      SUMDEN = 0.
      SUMNOM = 0.
      SUMDOS = 0.
         DO 501 IEKEV = 1,20
        EKEV = EGROUP(IEKEV,NSPEC)
      RMAX = 1.E8
```

```
C-----RESET RMAX IN FLAG EACH TIME ENERGY IS CHANGED
      FRCT = FRACT(IEKEV,NSPEC)
      IF(FRCT.EQ.0) GOTO 501
      WRITE(*,806) EKEV
C-----LET YOU KNOW PROGRAM IS RUNNING
      CALL PROTECT(DRF)
       WRITE(*,702) DRF
      SUMDEN = SUMDEN + TOTKRN * FRCT
      SUMNOM = SUMNOM + TDIRT * FRCT
      SUMDOS = SUMDOS + TOTDOS * FRCT
 501  CONTINUE
      DRF = SUMNOM/SUMDEN
      IF(NSPEC.EQ.4)WRITE(OUT,505)SUMDEN,SUMDOS,SUMNOM,DRF
      IF(NSPEC.EQ.3)WRITE(OUT,510)SUMDEN,SUMDOS,SUMNOM,DRF
 505  FORMAT(1X,15X,'1.12 Hr.',5X,2(G10.5,3X),'**********',3X,
     1 '**********',3X,G10.5,6X,G10.5)
 510  FORMAT(1X,15X,'RSS     ',5X,2(G10.5,3X),'**********',3X,
     1 '**********',3X,G10.5,6X,G10.5)
 500  CONTINUE
 302  FORMAT(1X,15X,6(G10.5,3X),3X,G10.5)
 803  FORMAT(1H0,15X,'E(KeV)',6X,
     1 ' KERNAL',6X,'R/hr/Ci*m2',4X,
     2 ' MFP1',4X,'D2 (meters)',2X,'TERRAIN KERNAL',9X,'DRF')
 808  FORMAT(1H0,15X,'Integration to 12 MFPs in air.')
 809  FORMAT(16X,'Radius to inside of disk in infinite plane = ',
     1 F9.3,' meters')
 804  FORMAT(16X,'Detector is 1 meter above smooth plane')
 620  FORMAT(16X,'Terrain factor = ',F12.4)
      STOP
      END
C
      SUBROUTINE PROTECT(DRF)
      REAL TOLER(10),DMFP(10),KERN,MU
      EXTERNAL DISK,GROUND
      COMMON/ENERGY/EKEV,MU,BU,W,THETA,DOVERW
      COMMON/KERNAL/TOTKRN,TOTDOS,TDIRT,XXJM1,D2,R1
      DATA  TOLER/1.E-4,1.E-4,1.E-4,1.E-4,1.E-4,1.E-4,
     1  1.E-4,1.E-4,1.E-3,1.E-2/
      DATA DMFP/.003,.01,.05,.1,.2,.5,1.,2.,5.,12./
C-----RHO = DENSITY OF AIR AT STP 0.001293 gm/cm**3
      RHO = 0.001293
       AMUEKV = AMU(EKEV)
       MU = AMUEKV * RHO
C-----DISTANCES ARE IN METERS, MU IN INVERSE CENTIMETERS, XJ IS IN MFPS
      TOTDOS = 0.
      TOTKRN = 0.
      TDIRT = 0.
      N1=0
      N2=0
      XDOSE = ROENTG(EKEV)
      DO 805 J = 1,10
```

```
      XJ = DMFP(J)
      TOL = TOLER(J)
C***** IF R1 IS GREATER THAN XJ DO NOT INTEGRATE BACKWARDS
      XJM1 = R1 * MU * 100.
      IF(XJ.LE.XJM1) GOTO 805
      N1 = N1 + 1
      D2 = XJ/MU/100.
            IF(N1.EQ.1) THEN
             XXJM1 = XJM1
            ELSE
             XJM1 = DMFP(J-1)
            END IF
      D1 = XJM1/MU/100.
        CALL SIMPS(D1,D2,TOL,KERN,DISK)
         DS = XDOSE * KERN
      TOTKRN = TOTKRN + KERN
      TOTDOS = TOTDOS + DS
        CALL SIMPS(D1,D2,TOL,DIRT,GROUND)
      TDIRT = TDIRT + DIRT
 805    CONTINUE
      DRF = TDIRT/TOTKRN
      END
C
      FUNCTION GROUND(R)
C******** POINT KERNAL FOR A DISK SOURCE
      REAL MU, HYP, MUCONC, MUDIRT, MFPG, MFPAIR,MFP,INDIR
      COMMON /ENERGY/ EKEV, MU, BU, W, THETA,DOVERW
      COMMON /FLAG/ RMAX
C     NSKIP = 0
      PI = 3.141592654
      HEIGHT = 1.0
C-----STANDARD REFERENCE POINT FOR A DOSE IS 1 METER FROM GROUND
C----- FIND THETA FROM R AND HEIGHT
           IF(R.GT.0.) THEN
             BETA = ATAN(HEIGHT/R)
           ELSE
             BETA = PI/2.
           ENDIF
      THETAR = THETA/180.*PI
      TAVE = 0.
      A = W
C----- IF BETA GREATER THAN THETA THERE IS NO ROUGH GROUND EFFECT
      IF(BETA.GT.THETAR) GOTO 100
C-----FIND A FROM W, THETA, AND BETA
      A = W * SIN(BETA) * COS(THETAR)/SIN(THETAR + BETA)
C----- A IS THAT PART OF GROOVE THAT IS NOT IN SHADDOW
C----- FIND AVERAGE THICKNESS OF EARTH INDIRECT PART PASSES THROU
      TAVE = W/4. * SIN(THETAR)/(COS(THETAR)*SIN(BETA))
C***** DO NOT WASTE TIME CALCULATING UNNECESSARY VALUES OF TAVE
C----- FIND D, THAT PART OF GROUND THAT IS STILL FLAT
 100  D = DOVERW * W
```

```
      DIRECT = (A + D)/(W+D)
 1    INDIR = (W - A)/(W+D)
C     WRITE(*,900)THETA,THETAR,DOVERW,W,TAVE,BETA,R,HEIGHT
      HYP = SQRT(HEIGHT*HEIGHT + R*R)
      MFPAIR = MU * HYP * 100.
      BUAIR = BUF(EKEV, MFPAIR)
      RHODRT = 1.3
C***** SPEC. GRAV. OF DIRT IS APPROX 1.3 SOURCE: MECH. ENG. HANDBOOK
      MUDIRT = RHODRT * MUCONC(EKEV)
      MFPG =  MUDIRT * TAVE
      IF(MFPG.GT.12) THEN
            TERAIN = 0.
            GOTO 20
      ENDIF
      BUF1 = BUF(EKEV,MFPG + MFPAIR)
      BUF2 = BUF(EKEV,MFPG)
      BUF3 = BCONC(EKEV,MFPG)
      TERAIN = INDIR* EXP(-MFPG) * BUF3 * BUF1/BUF2
 20   DISK1= .5 * BUAIR*EXP(-MFPAIR) * R/HYP**2.
      GROUND =  DISK1 * (DIRECT + TERAIN/BUAIR)
      RETURN
      END
C
      SUBROUTINE SIMPS(LOWER,UPPER, TOL, SUM, F)
C*****************************************************
C NUMERICAL INTEGRATION BY SIMPSON'S RULE.
C
      INTEGER IN, OUT, PIECES, I, P2
      REAL X, DELTA, LOWER, UPPER, SUM, TOL
      REAL ENDSUM, ODDSUM, SUM1, EVSUM
      COMMON /INOUT/ IN, OUT
C
      PIECES = 2
      DELTA = (UPPER - LOWER) / PIECES
      ODDSUM = F(LOWER + DELTA)
      EVSUM = 0.0
      ENDSUM = F(LOWER) + F(UPPER)
      SUM = (ENDSUM + 4 * ODDSUM) * DELTA / 3.0
 5    PIECES = PIECES * 2
            P2 = PIECES / 2
            SUM1 = SUM
            DELTA = (UPPER - LOWER) / PIECES
            EVSUM = EVSUM + ODDSUM
            ODDSUM = 0.0
            DO 10 I = 1, P2
            X = LOWER + DELTA * (2 * I - 1)
            ODDSUM = ODDSUM + F(X)
 10   CONTINUE
      SUM = (ENDSUM + 4.0 *ODDSUM + 2.0 * EVSUM) * DELTA / 3.0
      IF(ABS(SUM - SUM1) .GT. ABS(TOL * SUM)) GOTO 5
      RETURN
```

```
      END
C
      FUNCTION DISK(R)
C******** POINT KERNAL FOR A DISK SOURCE
      REAL MU, HYP
      COMMON /ENERGY/ EKEV, MU, BU, W, THETA,DOVERW
      A = 1.0
C-----STANDARD REFERENCE POINT FOR A DOSE IS 1 METER FROM GROUND
      HYP = SQRT(A*A + R*R)
      BU = BUF(EKEV, MU * HYP * 100.)
      DISK = .5 * BU*EXP(-MU*100.*HYP)*R/HYP**2.
      RETURN
      END
C
      FUNCTION AMU(EKEV)
C MASS ATTENUATION IN cm*2/gr
      REAL E(26), MUORHO(26), LOGINT
C-----AIR MASS ATTENUATION DATA FROM RADIOLOGICAL HEALTH HANDBOOK
C-----, JAN 1970, PG139
C
      DATA E/10.,15.,20.,30.,40.,50.,60.,80.,100.,150.,200.,300.,
     1 400.,500.,600.,800.,1000.,1500.,2000.,3000.,4000.,5000.,
     2 6000.,8000.,10000.,15000./
      DATA MUORHO/ 4.99,1.55,0.752,0.349,0.248,0.208,0.188,0.167,0.154,
     1 0.136,0.123,0.107,0.0954,0.0870,0.0805,0.0707,0.0636,
     2 0.0518,0.0445,0.0358,0.0308,0.0275,0.0252,0.0223,
     3 0.0204,0.0181/
C
C----USE LOG-LOG INTERPOLATION
      LOGINT(X,X1,X2,Y1,Y2) = EXP((ALOG(Y2)-ALOG(Y1))*
     1  (ALOG(X)-ALOG(X1))/(ALOG(X2)-ALOG(X1)) + ALOG(Y1))
C
C
      J=2
C-------use lowest two data points for energies below table
      IF(EKEV.LT.E(1)) GO TO 212
 200  IF(EKEV - E(J)) 212,211,210
 210  J = J + 1
      IF(J.LT.26) GOTO 200
C-------use highest two data points for energies above table
      GOTO 212
 211  AMU =  MUORHO(J)
      RETURN
 212  CONTINUE
      AMU = LOGINT(EKEV,E(J-1),E(J),MUORHO(J-1),MUORHO(J))
      RETURN
      END
C
      FUNCTION ROENTG(EKEV)
C%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
C     This function converts BUF adjusted flux to R*m**2/hr/Ci
```

```
C%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
      REAL E(26), MUORHO(26), LOGINT
C-----Air mass absorption data from NSRDS-NBS 29, 1969 pg 20 & 21
      DATA E/10.,15.,20.,30.,40.,50.,60.,80.,100.,150.,200.,300.,
     1 400.,500.,600.,800.,1000.,1500.,2000.,3000.,4000.,5000.,
     2 6000.,8000.,10000.,15000./
      DATA MUORHO/ 4.61,1.28,0.511,0.148,0.0669,.0406,.0305,.0243,
     1 .0234,.0250,.0268,.0288,.0295,.0296,.0295,.0289,.0278,
     2 .0254,.0234,.0205,.0186,.0174,.0164,.0152,.0145,.0132/
C
C----USE LOG-LOG INTERPOLATION
      LOGINT(X,X1,X2,Y1,Y2) = EXP((ALOG(Y2)-ALOG(Y1))*
     1  (ALOG(X)-ALOG(X1))/(ALOG(X2)-ALOG(X1)) + ALOG(Y1))
C
      J=2
C-------use lowest two data points for energies below table
      IF(EKEV.LT.E(1)) GO TO 212
 200  IF(EKEV - E(J)) 212,211,210
 210  J = J + 1
      IF(J.LT.26) GOTO 200
C-------use highest two data points for energies above table
      GOTO 212
 211  ROENTG =  MUORHO(J) * EKEV * 244.3365 /1000.
      RETURN
 212  CONTINUE
      ROENTG = LOGINT(EKEV,E(J-1),E(J),MUORHO(J-1),MUORHO(J)) *
     1  EKEV * 244.3365 /1000.
      RETURN
      END
C
      FUNCTION BUF(EKEV,MUR)
      REAL E(25), A1(25), A2(25), ALPHA1(25), ALPHA2(25), ALPHA3(25)
      REAL MUR, LOGINT, SEMINT
      COMMON /OLDJ/ EOLD, JOLD
      DATA E/15.,20.,30.,40.,50.,60.,80.,100.,150.,200.,300.,
     1 400.,500.,600.,800.,1000.,1500.,2000.,3000.,4000.,5000.,
     2 6000.,8000.,10000.,15000./
      DATA A1/1.258E1,4.960,1.039E1,1.183E2,5.106E2,
     1 1.641E3,1.477E3,1.503E3,1.242E3,1.206E3,
     2 1.251E3,1.182E3,1.232E3,4.316E3,1.102E3,
     3 1.123E3,2.941E2,4.159E2,1.162E2,1.928E1,
     4 1.251E1,1.047E1,1.011E1,8.889,6.661/
      DATA A2/-3.984E-1,-6.395E-1,-6.924E-1,-1.462E2,-6.189E2,
     1 -2.712E3,-2.543E3,-2.736E3,-2.317E3,-2.149E3,
     2 -1.756E3,-2.019E3,-1.664E3,-4.588E3,-1.308E3,
     3 -1.174E3,-2.179E2,-2.687E2,-6.740E1,-1.417E1,
     4 -6.071,-3.919,-3.046,-2.360,-1.496/
      DATA ALPHA1/-2.509E-2,-1.058E-3,-3.174E-2,-2.852E-2,-4.231E-2,
     1 -4.888E-2,-7.303E-2,-8.190E-2,-8.536E-2,-7.780E-2,
     2 -5.541E-2,-3.850E-2,-2.843E-2,-1.751E-2,-1.141E-2,
     3 -1.031E-2,-4.964E-2,-3.784E-2,-2.395E-2,-2.575E-2,
```

```
     4 -4.129E-2,-5.176E-2,-4.734E-2,-4.839E-2,-5.032E-2/
      DATA ALPHA2/3.955E-1,5.505E-1,9.030E-1,6.613E-3,-1.852E-2,
     1 -2.589E-2,-4.109E-2,-4.753E-2,-5.025E-2,-4.773E-2,
     2 -3.475E-2,-1.678E-2,-1.351E-2,-1.406E-2,-2.141E-3,
     3 -5.925E-3,-3.988E-2,-2.974E-2,-7.309E-3,2.054E-2,
     4 5.030E-2,7.394E-2,8.321E-2,9.146E-2,1.018E-1/
      DATA ALPHA3/-2.659E-2,3.524E-2,6.484E-2,6.739E-2,6.537E-2,
     1 6.546E-3,1.458E-3,-6.323E-3,-9.997E-3,-9.998E-3,
     2 1.528E-2,1.292E-2,2.686E-2,3.682E-2,4.240E-2,
     3 7.813E-2,-6.392E-2,-4.662E-2,-3.262E-2,-4.182E-2,
     4 -5.231E-2,-6.205E-2,-5.452E-2,-5.524E-2,-5.774E-2/
C***** BUILD UP FACTOR DATA FROM NUC SCI & END 78 PG74 1981
      BF(A,B,C,D,E,UR)= A*EXP(-C*UR)+B*EXP(-D*UR)+(1-A-B)*EXP(-E*UR)
C----USE LOG-LOG INTERPOLATION
      LOGINT(X,X1,X2,Y1,Y2) = EXP((ALOG(Y2)-ALOG(Y1))*
     1  (ALOG(X)-ALOG(X1))/(ALOG(X2)-ALOG(X1)) + ALOG(Y1))
      SEMINT(X,X1,X2,Y1,Y2) = EXP((ALOG(Y2)-ALOG(Y1))*
     1  (X-X1)/(X2-X1) + ALOG(Y1))
C***** DO NOT LOOK UP CONSTANTS IF YOU ARE NOT CHANGING ENERGY
      IF(EKEV.EQ.EOLD)THEN
      J = JOLD
      GOTO 212
      ENDIF
      EOLD = EKEV
C
      J=2
C-------use lowest two data points for energies below table
      IF(EKEV.LT.E(1)) GO TO 212
 200  IF(EKEV - E(J)) 212,211,210
 210  J = J + 1
      IF(J.LT.25) GOTO 200
C-------use highest two data points for energies above table
      GOTO 212
 211  IF(MUR.GT.40.) GOTO 213
      BUF = BF(A1(J),A2(J),ALPHA1(J),ALPHA2(J),ALPHA3(J),MUR)
C     WRITE(1,900)EKEV,BUF,J,A1(J),A2(J),ALPHA1(J),ALPHA2(J),ALPHA3(J)
      JOLD = J
      RETURN
 212  CONTINUE
      IF(MUR.GT.40.) GOTO 213
      X2=   BF(A1(J),A2(J),ALPHA1(J),ALPHA2(J),ALPHA3(J),MUR)
      X1=BF(A1(J-1),A2(J-1),ALPHA1(J-1),ALPHA2(J-1),ALPHA3(J-1),MUR)
      BUF = LOGINT(EKEV,E(J-1),E(J),X1,X2)
      JOLD = J
      RETURN
 213  CONTINUE
C-----IF MFPS ARE GT 40 INTERPRET FROM END OF RANGE
      X2=   BF(A1(J),A2(J),ALPHA1(J),ALPHA2(J),ALPHA3(J),40.)
      X1=BF(A1(J-1),A2(J-1),ALPHA1(J-1),ALPHA2(J-1),ALPHA3(J-1),40.)
      BUF2 = LOGINT(EKEV,E(J-1),E(J),X1,X2)
      X2=   BF(A1(J),A2(J),ALPHA1(J),ALPHA2(J),ALPHA3(J),35.)
```

```
      X1=BF(A1(J-1),A2(J-1),ALPHA1(J-1),ALPHA2(J-1),ALPHA3(J-1),35.)
      BUF1 = LOGINT(EKEV,E(J-1),E(J),X1,X2)
      BUF = SEMINT(MUR,35.,40.,BUF1,BUF2)
      JOLD = J
      RETURN
        END
C
      FUNCTION BCONC(EKEV,RMFP)
C-----THIS FUNCTION CALCULATES THE BUILD UP FACTOR IN CONCRETE OR
C-----CONCRETE LIKE MATERIALS FROM THE NBS SOLUTION USING 12 PARAMETERS
C-----BY EISENHAUER AND SIMMONS REF NUC SCI AND ENG 56,263-270,1975
C
C----- R IS IN MFPS
C
      REAL E(25), DO(25),MUC(25),LOGINT,MUCONC
      REAL A0(25),A1(25),A2(25),A3(25),A4(25)
      REAL B0(25),B1(25),B2(25),B3(25),B4(25)
      REAL*8 BFC
      COMMON /OLDJ2/ EOLD2, JOLD2
      DATA E/15.,20.,30.,40.,50.,60.,80.,100.,150.,200.,300.,
     1 400.,500.,600.,800.,1000.,1500.,2000.,3000.,4000.,5000.,
     2 6000.,8000.,10000.,15000./
      DATA MUC/8.0100,3.4450,1.1180,0.5588,0.3608,0.2734,0.2004,0.1704,
     1 0.1399,0.1250,0.1073,0.0958,0.0873,0.0807,0.0709,
     2 0.0637,0.0519,0.0448,0.0365,0.0319,0.0290,0.0270,0.0245,
     3 0.0231,0.0215/
      DATA DO/0.1589,0.1487,0.1327,0.1200,0.1128,
     1 0.1118,0.1215,0.1376,0.1791,0.2149,0.2690,
     2 0.3088,0.3409,0.3674,0.4085,0.4404,0.4761,
     3 0.5280,0.5679,0.5938,0.6158,0.6241,0.6425,0.6560,0.6676/
      DATA A0/1.1135E-2,2.4283E-2,0.06645,0.11734,0.15910,
     1 0.18644,0.22372,0.24651,0.27760,0.29820,0.31837,
     2 0.32929,0.33559,0.33965,0.34413,0.34678,0.35110,
     3 0.35445,0.35691,0.35425,0.34788,0.33878,0.31686,
     4 0.29369,0.24038/
      DATA A1/-0.0011583,-0.0024618,-0.0060622,-0.0092903,
     1 -0.015356,+0.025044,-0.010144,0.040674,0.021783,
     2 0.029893,0.012225,0.0095543,0.0044976,0.0073127,
     3 0.0091422,0.0098983,0.010016,0.0099221,0.0078632,
     4 0.010371,0.040628,0.030809,-0.013397,-0.016610,-0.0029308/
      DATA A2/5.483E-04,1.2409E-03,3.9089E-03,8.6343E-03,
     1 1.5169E-02,1.1833E-02,3.7832E-02,3.2059E-02,2.9878E-02,
     2 4.8446E-02,
     3 5.5001E-02,5.0474E-02,2.2018E-02,2.7012E-02,2.2857E-02,
     4 2.0876E-02,1.9785E-02,1.9206E-02,2.1801E-02,3.9089E-02,
     5 -9.3940E-03,-8.8533E-03,2.8838E-02,2.7261E-02,-1.9101E-02/
      DATA A3/2.1503E-04,5.0984E-04,1.7224E-03,4.0328E-03,
     1 7.5754E-03,1.3153E-03,3.0337E-02,2.6207E-02,3.1915E-02,
     2 8.2357E-02,1.0486E-01,1.1029E-01,3.4039E-02,3.1744E-02,
     3 4.4123E-02,5.0435E-02,5.2275E-02,4.9103E-02,3.9006E-02,
     4 2.9853E-02,2.8888E-02,2.5095E-02,1.8330E-02,1.4079E-02,
```

```
      5 2.2817E-02/
       DATA A4/4.2382E-05,1.0829E-04,3.9905E-04,1.0308E-03,
      1 2.2527E-03,0.00000000,1.2457E-02,3.1514E-06,5.0041E-02,
      2 -1.4638E-04,-8.6411E-04,-6.3551E-08,1.0539E-01,9.4382E-02,
      3 7.3309E-02,5.9498E-02,4.0714E-02,3.2172E-02,2.2187E-02,
      4 2.0073E-03,6.7348E-05,3.5701E-03,1.5406E-03,3.6397E-07,
      5 9.8532E-03/
       DATA B0/0.57471,0.56384,0.54853,0.53850,0.53787,
      1 0.54758,0.57172,0.60062,0.65913,0.69464,0.73934,
      2 0.76455,0.78166,0.79363,0.80851,0.81671,0.82277,
      3 0.81861,0.80467,0.79201,0.78176,0.77269,0.75988,
      4 0.75116,0.73974/
       DATA B2/0.72706,0.71518,0.69814,0.68724,0.68395,
      1 0.90637,0.69136,0.86298,0.77287,0.84634,0.82998,
      2 0.82998,0.76467,0.79645,0.80369,0.80482,0.79832,
      3 0.79546,0.81708,0.85749,0.72880,0.63341,0.85214,
      4 0.86119,0.55119/
       DATA B1/0.42393,0.41368,0.39364,0.36010,0.28648,
      1 0.70718,0.80330,0.69185,0.68532,0.71979,0.68807,
      2 0.65925,0.56762,0.58849,0.57175,0.55269,0.52360,
      3 0.50858,0.46877,0.30734,0.83930,0.83961,0.57962,
      4 0.56105,0.85134/
       DATA B3/0.87317,0.86506,0.85649,0.85396,0.85703,
      1 1.00436,0.85532,0.98931,0.87818,1.01431,1.00389,
      2 1.00620,0.87305,0.90888,0.91929,0.91859,0.91265,
      3 0.90861,0.91102,0.96145,0.96388,0.94894,0.95976,
      4 0.97377,0.86292/
       DATA B4/0.96440,0.96154,0.95995,0.96110,0.96562,
      1 1.00000,0.98034,1.17560,1.00645,1.09682,1.07209,
      2 1.34178,1.00139,0.99831,0.99455,0.99168,0.98767,
      3 0.98542,0.98406,1.01558,1.10090,1.00529,1.01101,
      4 1.22902,0.97741/
       BFC(R,U,A0,A1,A2,A3,A4,B0,B1,B2,B3,B4,D0) = 1 + (
      1 A0*U*R*DEXP(-DBLE(J*R/B0))+A1*(U*R/B1)**2*DEXP(-DBLE(U*R/B1))+
      2 A2 * (U*R/B2)**2 * DEXP(-DBLE(U*R/B2)) +
      3 A3 * (U*R/B3)**2 * DEXP(-DBLE(U*R/B3)) +
      4 A4*(U*R/B4)**2*DEXP(-DBLE(U*R/B4)))/(D0*DEXP(-DBLE(U*R)))
C----USE LOG-LOG INTERPOLATION
       LOGINT(X,X1,X2,Y1,Y2) = EXP((ALOG(Y2)-ALOG(Y1))*
      1  (ALOG(X)-ALOG(X1))/(ALOG(X2)-ALOG(X1)) + ALOG(Y1))
       R = RMFP / MUCONC(EKEV)
C                  WRITE(*,1000) 'BCONC  2',EKEV
C****** DO NOT LOOK UP CONSTANTS IF YOU ARE NOT CHANGING ENERGY
       IF(EKEV.EQ.EOLD2)THEN
       J = JOLD2
       GOTO 212
       ENDIF
       EOLD2 = EKEV
C
       J=2
C-------use lowest two data points for energies below table
```

```
      IF([illegible]V.LT.E(1)) GO TO 212
 200  IF([illegible] - E(J)) 212,211,210
 210  J = [illegible] + 1
      IF(J.LT.25) GOTO 200
C-------use highest two data points for energies above table
      GOTO 212
 211  BCONC=BFC(R,MUC(J),A0(J),A1(J),A2(J),A3(J),A4(J),B0(J),B1(J),
     1 B2(J),B3(J),B4(J),D0(J))
      URCONC = R * MUC(J)
      JOLD2 = J
      RETURN
 212  CONTINUE
      X2=BFC(R,MUC(J),A0(J),A1(J),A2(J),A3(J),A4(J),B0(J),B1(J),B2(J),
     1 B3(J),B4(J),D0(J))
      K = J - 1
       X1=BFC(R,MUC(K),A0(K),A1(K),A2(K),A3(K),A4(K),B0(K),B1(K),B2(K),
     1 B3(K),B4(K),D0(K))
      BCONC = LOGINT(EKEV,E(J-1),E(J),X1,X2)
      URCONC = R * LOGINT(EKEV,E(J-1),E(J),MUC(J-1),MUC(J))
      JOLD2 = J
      RETURN
        END
C
      REAL FUNCTION MUCONC(EKEV)
C-----this fucntion calculates mu over rho for concrete in cm2/gr
      REAL E(25), MUORHO(25), LOGINT
C-----mass attenuation data from Nuc Sci & Eng 56 pr 267, 1975
C
      DATA E/15.,20.,30.,40.,50.,60.,80.,100.,150.,200.,300.,
     1 400.,500.,600.,800.,1000.,1500.,2000.,3000.,4000.,5000.,
     2 6000.,8000.,10000.,15000./
      DATA MUORHO/8.0100,3.4450,1.1180,0.5589,0.3608,0.2734,0.2004,
     1 0.1734,0.1399,0.1250,0.1073,0.0958,0.0873,0.0807,0.0709,
     2 0.0637,0.0519,0.0448,0.0365,0.0319,0.0290,0.0270,0.0245,
     3 0.0231,0.0215/
C
C----USE LOG-LOG INTERPOLATION
      LOGINT(X,X1,X2,Y1,Y2) = EXP((ALOG(Y2)-ALOG(Y1))*
     1  (ALOG(X)-ALOG(X1))/(ALOG(X2)-ALOG(X1)) + ALOG(Y1))
C
C
      J=2
C-------use lowest two data points for energies below table
      IF(EKEV.LT.E(1)) GO TO 212
 200  IF(EKEV - E(J)) 212,211,210
 210  J = J + 1
      IF(J.LT.26) GOTO 200
C-------use highest two data points for energies above table
      GOTO 212
 211  MUCONC =  MUORHO(J)
      RETURN
```

```
212   CONTINUE
      MUCONC = LOGINT(EKEV,E(J-1),E(J),MUORHO(J-1),MUORHO(J))
      RETURN
      END
```

APPENDIX B

FALLOUT PROGRAM DESCRIPTION AND LISTING

The Fallout program calculates the DRFs for a fallout source when the detector is centered inside a structure. The program model is discussed in Section 2.7. Required input includes the equivalent height and radius of the structure, the mass thickness of the roof and walls and the three ground roughness factors w, d/w and ψ .

When the Fallout program is run, it will ask for input data as shown in Figure 27. The first input required is a title and date for the output listing. The program then asks for the equivalent radius and height of the structure, followed by the mass thicknesses of the wall and roof. The program then prompts the user with a few suggested values for the three ground roughness factors (see Section 2.6.2). Other values for the ground roughness factors may be used. The program then calculates the resultant DRF's for the 1-Hr. bomb fallout spectra, the PWR-2 (RSS) fallout spectra, the TMI fallout spectra and the SL-1 fallout spectra followed by the DRFs for energies from 15 KeV to 15 MeV. A typical output listing in shown in Table 14.

```
B>fallout
INPUT TITLE/DATE OF OUTPUT
Small Wood House. 16 Sept 1984
INPUT EQUIVALENT RADIUS OF STRUCTURE IN METERS  5.
INPUT EQUIVALENT HEIGHT OF STRUCTURE IN METERS  5.
WALL MASS THICKNESS IN gr/cm**2  10.
ROOF MASS THICKNESS IN gr/cm**2  10.
Three ground factors must be input
 W - The charactoristic trough width
 D/W - The ratio of flat surface to trough
 and PSI - The charactoristic trough angle.

   The following are suggested values:
   SURFACE            W            D/W

   Smooth plane       0.            1.
   Paved Area       0.3941          1.
   Lawn             2.3698        0.959
   Gravelled Area   7.4678        0.897
   Plowed Field     25.8207       0.839

   PSI = 45. degrees


INPUT PSI (degrees) 45.
INPUT W 2.3698
INPUT D/W .959
```

FIGURE 27 Typical Computer CRT Display During Initiation of Fallout Program.

The program also calculates the unprotected exposure in R per Curie of fallout per square meter. The exposures from the roof source and ground source are calculated and summed to give the total exposure. The fraction of the total exposure from the roof source is given as the roof contribution (ROOF CONT.). This is followed by the DRFs and the ratio of the DRFs to the DRF for the 1-Hr. bomb fallout spectra. The last column of data is the exposure one would receive from an interior fallout source of 1 Curie per square meter. The program assumes one gamma per disintegration for the 1 Hr. bomb fallout, the PWR-2 fallout (RSS-Fallout) and the individual gamma energy calculations,.

The program is written in _Microsoft_ FORTRAN 3.13. This is a version of FORTRAN 77. There are no non-standard FORTRAN commands in the program. The program was run on a _Texas Instruments Professional Computer_ (PC) which uses an _8088_ processor and an _8087_ co-processor. The program was run under the _MS-DOS_ 2.11 operating system. However, it should run on any computer capable of using FORTRAN 77. The program takes approximately 45 minutes running time. Caution, the program is written is FORTRAN, the input _requires_ decimal points. The program may not converge to an answer for low energies (15 and 20 KeV) for wall thickness greater than about 20 gr/cm^2. This is because the exposures are less than 8.43E-37, which is the limit of the single

precision data type used for real variables.

The MAIN program directs the input and output of the program data. Subroutine SIMPS carries out the integrations by using Simpson's rule. The number of increments is automatically increased until the desired accuracy is obtained. Subroutine PROTECT speeds the integration of the disk source by dividing the disk into rings which converge to integrals faster. Function DISKIN finds the kernel for the hypothetical infinite smooth disk source. Function GROUND calculates the kernel for the fallout using the methods developed in Section 2.7. Function DISKRF calculated the kernel for the roof source.

Function AMU finds the mass attenuation coefficient for air. Function BUF finds the buildup factor for air. Function MUCONC finds the mass attenuation coefficient for the ground, roof and walls. Function BCONC finds the buildup factor for the ground, roof and the walls. Function ROENTG finds the factor for converting flux to exposure.

The listing of the Fallout program follows.

```
      PROGRAM HOUSE
      CHARACTER CTITLE*91
      INTEGER IN, OUT
      REAL E(20), MFP1, LININT, INSIDE
      REAL EGROUP(20,4), FRACT(20,4)
      EXTERNAL  DISKIN, GROUND, DISKRF
      COMMON /ENERGY/ EKEV,W, PSI, DOVERW
      COMMON /SIZE/ RTHICK,WTHICK,BHGHT,BRAD
      COMMON /INOUT/ IN, OUT
      COMMON /OLDJ/ EOLD, JOLD
      COMMON /OLDJ2/ EOLD2,JOLD2
C^^^^^^ NOTE RADII ARE IN METERS, ENERGIES IN KeV, DENSITIES IN gr/cm*2
C
      DATA E/15.,20.,30.,40.,50.,60.,80.,100.,150.,200.,300.,
     1 400.,500.,600.,662.,800.,1000.,1173.,1332.,1500.,
     2 2000.,3000.,4000.,5000.,6000.,8000.,10000.,15000./
      DATA EGROUP / 25.,75.,150.,250.,350.,500.,700.,
     1 900.,1165.,1500.,1830.,2250.,2750.,3500.,4500.,5*0.,
     2 50.,300.,750.,1500.,2500.,15*0.,
     3 723.,637.,364.,284.,80.,15*0.,
     4 81.,284.,364.,637.,662.,723.,14*0./
      DATA FRACT /.0271,.0137,.0737,.0476,.0929,.1373,.1717,.1627,
     1 .0839,.0957,.0299,.0397,.0148,.0042,.0001,5*0.,
     2 .1696,.2431,.2760,.2183,.0930,15*0.,
     3 .016,.068,.82,.054,.026,15*0.,
     4 .0245,.0509,.7736,.0642,.0401,.0151,14*0./
C******* LINEAR INTERPOLATION FUNCTION
      LININT(X,X1,X2,Y1,Y2) = (Y2-Y1)*(X-X1)/(X2-X1) + Y1
C^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
C^ATTEMPT TO CONTROL EPSON FX-80 PRINTER FROM FORTRAN TO COMPRESS PRINT
          OPEN (1,FILE='LPT1',STATUS='NEW',ACCESS='DIRECT'
     1    ,FORM='UNFORMATTED',RECL=1)
          WRITE (1)27,15
          CLOSE (1)
          OPEN(1,FILE='LPT1')
C^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
      PI = 3.141592654
      OUT = 1
      EOLD = 0.0
      EOLD2 = 0.0
      IN = 0
      NSPEC = 0
C%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
C%%%%% Routines for inputing and printing given data.
C%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
      WRITE(*,290)
 290  FORMAT(1X,'INPUT TITLE/DATE OF OUTPUT')
      READ(*,291)CTITLE
      WRITE(OUT,807)
      WRITE(OUT,292)CTITLE
      WRITE(OUT,808)
```

```
      WRITE(OUT,804)
 330  WRITE(*,301)
 331  FORMAT(1X,'INPUT EQUIVALENT RADIUS OF STRUCTURE IN METERS  ',\)
 302  READ (*,303) BRAD
 303  FORMAT(F13.6)
      WRITE(*,311)
 311  FORMAT(1X,'INPUT EQUIVALENT HEIGHT OF STRUCTURE IN METERS  ',\)
      READ (*,303) BHGHT
      WRITE(*,321)
 321  FORMAT(1X,'WALL MASS THICKNESS IN gr/cm**2  ',\)
      READ (*,303) WTHICK
      WRITE(*,331)
 331  FORMAT(1X,'ROOF MASS THICKNESS IN gr/cm**2  ',\)
      READ (*.303) RTHICK
C**********************************************************************
      WRITE(*,600)
      WRITE(*,610)
      READ(*,303) PSID
      PSI = PSID/180.*PI
      WRITE(*,611)
      READ(*,303) W
      WRITE(*,612)
      READ(*,303) DOVERW
 600  FORMAT(1X,'Three ground factors must be input',/,
     1 '  W - The charactoristic trough width',/,
     2 '  D/W - The ratio of flat surface to trough',/,
     3 '  and PSI - The charactoristic trough angle.',/,/,
     4 '    The following are suggested values:',/,
     5 '    SURFACE            W           D/W',/,/,
     6 '    Smooth plane     . 0.           1.',/,
     7 '    Paved Area      0.3941         1.',/,
     8 '    Lawn            2.3698         0.959',/,
     9 '    Gravelled Area  7.4678         0.897',/,
     A '    Plowed Field    25.8207        0.839',/,/,
     B '    PSI = 45. degrees',/,/)
 610  FORMAT(1X,'INPUT PSI (degrees) ',\)
 611  FORMAT(1X,'INPUT W ',\)
 612  FORMAT(1X,'INPUT D/W ',\)
      WRITE(OUT,304)BRAD
      WRITE(OUT,314)BHGHT
      WRITE(OUT,324)WTHICK
      WRITE(OUT,334)RTHICK
      WRITE(OUT,621)
      WRITE(OUT,622) PSID
      WRITE(OUT,623) W
      WRITE(OUT,624) DOVERW
      WRITE(OUT,803)
C*****************************************************************
C**************INPUT TITLE FOR  LISTING***************************
 807  FORMAT(1H0,25X,'HOUSE WITH SEMI-INFINITE DISK SOURCE IN AIR',
     1 ' WITH GROUND FACTORS. 24 JULY 1984')
```

```
C*********************************************************************
 832  FORMAT(1X,25X,F7.1,5X,7(G9.4,2X),4X,G9.4)
 833  FORMAT(1H0,25X,'E(KeV)',3X,
     1 ' UNPROTECTED',3X,'ROOF',6X,
     2 'GROUND',3X,'TOTAL EXP.',2X,'ROOF CONT.',3X,'DRF',3X,
     3 'RATIO TO 1.12 Hr.',2X,'INSIDE')
 838  FORMAT(1H0,25X,'Integration to 12 MFPs in air.')
 304  FORMAT(1X,25X,'Equivalent radius of structure = ',
     1 F9.3,' meters')
 314  FORMAT(1X,25X,'Equivalent height of structure = '
     1 F9.3,' meters')
 324  FORMAT(1X,25X,'Wall mass thickness = ',
     1 F9.3,' gr/cm2')
 334  FORMAT(1X,25X,'Roof mass thickness = ',
     1 F9.3,' gr/cm2')
 834  FORMAT(1X,25X,'Detector is 1 meter above smooth plane')
 621  FORMAT(1X,25X,'The Ground Factors are:')
 622  FORMAT(1X,30X,'The trough angle PSI = ',F12.4,' degrees')
 623  FORMAT(1X,30X,'The charactoristic trough width W = ',F12.4)
 624  FORMAT(1X,30X,'The ratio of flat to trough D/W = ',F12.4)
 505  FORMAT(1X,25X,'1.12 Hr.    ',1X,7(G9.4,2X),4X,G9.4)
 513  FORMAT(1X,25X,'RSS-Fallout',1X,7(G9.4,2X),4X,G9.4)
 506  FORMAT(1X,25X,'TMI-Fallout',1X,7(G9.4,2X),4X,G9.4)
 507  FORMAT(1X,25X,'SL1-Fallout',1X,7(G9.4,2X),4X,G9.4)
 291  FORMAT(A91)
 292  FORMAT(1H0,25X,A91)
C*********************************************************************
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
C@@@@@ ROUTINE TO FIND DRFS FOR SPECTRA
      DO 500 NSPEC = 1,4,+1
      SUMGK = 0.
      SUMGE = 0.
      SUMUK = 0.
      SUMUE = 0.
      SUMRK = 0.
      SUMRE = 0.
      TEXIN = 0.
      DO 501 IEKEV = 1,20
      EKEV = EGROUP(IEKEV,NSPEC)
      FRCT = FRACT(IEKEV,NSPEC)
      IF(FRCT.EQ.0) GOTO 501
      WRITE(*,806) EKEV
C-----LET YOU KNOW PROGRAM IS RUNNING
      EXPOSE = ROENTG(EKEV)
      CALL PROTECT(0.,DISKIN,UNPKRN)
      CALL PROTECT(BRAD,GROUND,PKRN)
      CALL SIMPS(0.,BRAD,1.E-5,PROOF,DISKRF)
      CALL SIMPS(0 ,BRAD,1.E-5,INSIDE,DISKIN)
      TEXIN = TEXIN + INSIDE * EXPOSE * FRCT
      SUMUK = SUMUK + UNPKRN * FRCT
      SUMUE = SUMUE + UNPKRN * EXPOSE *FRCT
```

```
      SUMGK = SUMGK + PKRN *FRCT
      SUMGE = SUMGE + PKRN * EXPOSE *FRCT
      SUMRK = SUMRK + PROOF * FRCT
      SUMRE = SUMRE + PROOF * EXPOSE * FRCT
 501  CONTINUE
      TOTKRN = SUMGK + SUMRK
      TOTEXP = SUMGE + SUMRE
      DRF = TOTEXP/SUMUE
      IF(NSPEC.EQ.1) DRFBMB = DRF
      RATIO = DRF/DRFBMB
      RCONT = SUMRE/TOTEXP
      IF(NSPEC.EQ.1)WRITE(OUT,505)SUMUE,SUMRE,SUMGE,TOTEXP,
     1 RCONT,DRF,RATIO,TEXIN
      IF(NSPEC.EQ.2)WRITE(OUT,510)SUMUE,SUMRE,SUMGE,TOTEXP,
     1 RCONT,DRF,RATIO,TEXIN
      IF(NSPEC.EQ.3)WRITE(OUT,506)SUMUE,SUMRE,SUMGE,TOTEXP,
     1 RCONT,DRF,RATIO,TEXIN
      IF(NSPEC.EQ.4)WRITE(OUT,507)SUMUE,SUMRE,SUMGE,TOTEXP,
     1 RCONT.DRF,RATIO,TEXIN
 500  CONTINUE
C%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
C%%%%% ROUTINE FOR GENERATING ENERGY/DRF TABLE
C%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
        DO 801 IEKEV = 28,1,-1
       EKEV = E(IEKEV)
      WRITE(*,806) EKEV
 806  FORMAT(1X,'E(KeV) = ',G10.5,\)
C-----LET YOU KNOW PROGRAM IS RUNNING
      EXPOSE = ROENTG(EKEV)
      CALL PROTECT(0.,DISKIN,UNPKR)
      CALL PROTECT(BRAD,GROUND,PRK)
      CALL SIMPS(0.,BRAD,1.E-5,PROOF,DISKRF)
      CALL SIMPS(0.,BRAD,1.E-5,INSIDE,DISKIN)
      EXIN = INSIDE * EXPOSE
      EXPUNP = UNPKR * EXPOSE
      EXPPR= PRK * EXPOSE
      EXPRF = PROOF * EXPOSE
      TOTEXP = EXPPR + EXPRF
            IF(TOTEXP.LT.1.E-30) THEN
                 RCONT = .8888888E33
            ELSE
                 RCONT = EXPRF/TOTEXP
            ENDIF
               IF(EXPUNP.LT.1.E-30) THEN
                     DRF = .8888888E33
               ELSE
                     DRF = TOTEXP/EXPUNP
               ENDIF
      RATIO = DRF/DRFBMB
      WRITE(OUT,802)EKEV,EXPUNP,EXPRF,EXPPR,TOTEXP,RCONT,DRF,RATIO,EXIN
 801       CONTINUE
```

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 300  CONTINUE
C33333333333333333333333333333333333333333333333333333333333333333333333333
      STOP
      END
C-sub
      SUBROUTINE PROTECT(R1,DISK,TOTKRN)
      REAL TOLER(10),DMFP(10),KERN,MFP
C     EXTERNAL DISK,GROUND,DISKIN
      COMMON/ENERGY/EKEV,W,PSI,DOVERW
      COMMON /SIZE/ RTHICK,WTHICK,BHGHT,BRAD
      DATA  TOLER/1.E-4,1.E-4,1.E-4,1.E-4,1.E-4,1.E-4,
     1  1.E-4,1.E-4,1.E-3,1.E-2/
      DATA DMFP/.003,.01,.05,.1,.2,.5,1.,2.,5.,10./
C-----RHO = DENSITY OF AIR AT STP 0.001293 gm/cm**3
      RHO = 0.001293
       AMUEKEV = AMU(EKEV)
       MFP = AMUEKEV * RHO *100.
C-----DISTANCES ARE IN METERS, MU IN INVERSE CENTIMETERS, XJ IS IN MFPS
      TOTKRN = 0.
      N1=0
      DO 805 J = 1,10
      XJ = DMFP(J)
      TOL = TOLER(J)
C***** IF R1 IS GREATER THAN XJ DO NOT INTEGRATE BACKWARDS
      XJM1 = R1 * MFP
      IF(XJ.LE.XJM1) GOTO 805
      N1 = N1 + 1
      D2 = XJ/MFP
            IF(N1.EQ.1) THEN
             XXJM1 = XJM1
            ELSE
             XJM1 = DMFP(J-1)
            END IF
      D1 = XJM1/MFP
        CALL SIMPS(D1,D2,TOL,KERN,DISK)
         DS = XDOSE * KERN
      TOTKRN = TOTKRN + KERN
 805    CONTINUE
      RETURN
      END
C
      FUNCTION GROUND(R)
C******** POINT KERNAL FOR A DISK SOURCE
C******** This function calculates the kernal for a cylindrical wall
C******** with a ground roughness shielding factor
      REAL HYP, MUCONC, MFPGRN, MUC,INDIR
      REAL MFPWAL,ICOS, MUAIR,MFPT,MFPAIR,MFPBU
      COMMON /ENERGY/ EKEV,W, PSI, DOVERW
      COMMON /SIZE/ RTHICK,WTHICK,BHGHT,BRAD
C-----STANDARD REFERENCE POINT FOR A DOSE IS 1 METER FROM GROUND
      PI = 3.141592654
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```
      HEIGHT = 1.
      HYP = SQRT(HEIGHT**2.+ R*R)
      ICOS = HYP/R
      MUAIR = AMU(EKEV) * 0.001293 * 100.
      MFPAIR = MUAIR * ICOS * (R-BRAD-.2)
C-----Assume wall is .2 meters thick
      RHODRT = 1.3
C***** SPEC. GRAV. OF DIRT IS APPROX 1.3 SOURCE: MECH. ENG. HANDBOOK
      MUC = MUCONC(EKEV)
      MFPWAL = ICOS * MUC * WTHICK
      MFPBU = MUAIR * BRAD
      MFPT = MFPAIR + MFPWAL + MFPBU
      IF(MFPT.GT.12.) THEN
            GROUND = 0.
            RETURN
      ENDIF
C+++++ Find BETA from R and Height
      IF(R.GT.0.) THEN
            BETA = ATAN(HEIGHT/R)
      ELSE
            BETA = PI/2.
      ENDIF
C
      TAVE = 0.
      A = W
      DIRECT = 1.
      INDIR = 0.
      IF(W.LE.0.) GOTO 20
C+++++ if BETA is greater than Psi, there is of rough ground effect
      IF(BETA.GT.PSI) GOTO 20
C+++++ find A from W, PSI and BETA
C+++++ A is that part of the trough that is not in shaddow
      A = W * SIN(BETA) * COS(PSI)/SIN(BETA + PSI)
C+++++ Find the average thickness of earth indirect part passes throu
      TAVE = W/4. * SIN(PSI)/(COS(PSI)*SIN(BETA))
 100  CONTINUE
      D = DOVERW * W
      DIRECT = (A + D)/(W + D)
      INDIR = (W - A)/ (W + D)
      MFPGRN = MUC * RHODRT * TAVE
      IF(MFPGRN.GE.12.) THEN
            TERAIN = 0.
            GOTO 20
      ENDIF
C-------Find Build-Up-Factor for fraction that encounters the ground
      BUF1 = BCONC(EKEV,MFPGRN)
      BUF2 = BUF(EKEV,MFPAIR + MFPGRN)
      BUF3 = BUF(EKEV,MFPGRN)
      BUF4 = BCONC(EKEV,MFPGRN+MFPAIR+MFPWAL)
      BUF5 = BCONC(EKEV,MFPGRN + MFPAIR)
      BUF6 = BUF(EKEV,MFPGRN+MFPT)
```

```
      BUF7 = BUF(EKEV,MFPGRN+MFPAIR+MFPWAL)
      BUT1 = BUF1 * BUF2/BUF3 * BUF4/BUF5 * BUF6/BUF7
      TERAIN = INDIR * EXP(-(MFPGRN+MFPT)) * BUT1
 23   CONTINUE
C------- Find Build-Up Factor for fraction that missed the ground
      BUF1 = BUF(EKEV,MFPAIR)
      BUF2 = BCONC(EKEV,MFPWAL+MFPAIR)
      BUF3 = BCONC(EKEV,MFPAIR)
      BUF4 = BUF(EKEV,MFPAIR+MFPWAL+MFPBU)
      BUF5 = BUF(EKEV,MFPAIR+MFPWAL)
      BUT2 = BUF1 * BUF2/BUF3 * BUF4/BUF5
      DISK1= DIRECT * BUT2 * EXP(-MFPT)
      GROUND =  .5 * R/HYP**2. * (DISK1 + TERAIN)
      RETURN
      END
C
      FUNCTION DISKRF(R)
C******** POINT KERNAL FOR A DISK SOURCE
C******** This function calculates kernal for roof
      REAL  HYP,ISIN,MUCONC,MFP
      COMMON /ENERGY/ EKEV, W, PSI, DOVERW
      COMMON /SIZE/ RTHICK,WTHICK,BHGHT,BRAD
      IF(BHGHT.LT.1.) THEN
            PAUSE 'PROGRAM ABORT -- BUILDING TOO SHORT'
      ENDIF
      A = BHGHT -1. + .2
C-----STANDARD REFERENCE POINT FOR A DOSE IS 1 METER FROM GROUND
      HYP = SQRT(A*A + R*R)
      ISIN = HYP/A
      AIRMFP = AMU(EKEV) * HYP * .001293 * 100.
      CONMFP = MUCONC(EKEV) * RTHICK * ISIN
      MFP = AIRMFP + CONMFP
      IF(MFP.GT.80.) THEN
            DISKRF = 0.
            RETURN
      ENDIF
      BU = BCONC(EKEV,CONMFP)*BUF(EKEV,MFP)/BUF(EKEV,CONMFP)
      DISKRF = .5 * BU * R/HYP**2. * EXP(-MFP)
      RETURN
      END
C-
      FUNCTION DISKIN(R)
C******** POINT KERNAL FOR A DISK SOURCE
C******** This function calculates kernal for infinite smooth plane
      REAL MFP, HYP
      COMMON /ENERGY/ EKEV, W, PSI, DOVERW
C-----STANDARD REFERENCE POINT FOR A DOSE IS 1 METER FROM GROUND
      HYP = SQRT(1. + R*R)
      MFP = AMU(EKEV) * .001293 * 100. * HYP
      BU = BUF(EKEV, MFP)
      SA = 1.
```

```
      DISKIN = .5 * BU*SA*EXP(-MFP)*R/HYP**2.
      RETURN
      END
C-
      SUBROUTINE SIMPS(LOWER,UPPER, TOL, SUM, F)
C*****************************************************
C NUMERICAL INTEGRATION BY SIMPSON'S RULE.
C
      INTEGER IN, OUT, PIECES, I, P2
      REAL X, DELTA, LOWER, UPPER, SUM, TOL
      REAL ENDSUM, ODDSUM, SUM1, EVSUM
      COMMON /INOUT/ IN, OUT
      PIECES = 2
      DELTA = (UPPER - LOWER) / PIECES
      ODDSUM = F(LOWER + DELTA)
      EVSUM = 0.0
      ENDSUM = F(LOWER) + F(UPPER)
      SUM = (ENDSUM + 4 * ODDSUM) * DELTA / 3.0
 5    PIECES = PIECES * 2
            P2 = PIECES / 2
            SUM1 = SUM
            DELTA = (UPPER - LOWER) / PIECES
            EVSUM = EVSUM + ODDSUM
            ODDSUM = 0.0
            DO 10 I = 1, P2
            X = LOWER + DELTA * (2 * I - 1)
            ODDSUM = ODDSUM + F(X)
 10   CONTINUE
      SUM = (ENDSUM + 4.0 *ODDSUM + 2.0 * EVSUM) * DELTA / 3.0
C**** WRITE (*,100) LOWER,UPPER,SUM,PIECES
 100  FORMAT(1X,'LOWER',G14.7,'UPPER',G14.7,' SUM',G14.7,'PIECES',I3)
      IF(ABS(SUM - SUM1) .GT. ABS(TOL * SUM)) GOTO 5
      RETURN
      END
C
C
C-
      FUNCTION AMU(EKEV)
C MASS ATTENUATION IN cm*2/gr
      REAL E(26), MUORHO(26), LOGINT
C-----AIR MASS ATTENUATION DATA FROM RADIOLOGICAL HEALTH HANDBOOK
C-----, JAN 1970, PG139
C
      DATA E/10.,15.,20.,30.,40.,50.,60.,80.,100.,150.,200.,300.,
     1 400.,500.,600.,800.,1000.,1500.,2000.,3000.,4000.,5000.,
     2 6000.,8000.,10000.,15000./
      DATA MUORHO/ 4.99,1.55,0.752,0.349,0.248,0.208,0.188,0.167,0.154,
     1 0.136,0.123,0.107,0.0954,0.0870,0.0805,0.0707,0.0636,
     2 0.0518,0.0445,0.0358,0.0308,0.0275,0.0252,0.0223,
     3 0.0204,0.0181/
C
```

```
C----USE LOG-LOG INTERPOLATION
      LOGINT(X,X1,X2,Y1,Y2) = EXP((ALOG(Y2)-ALOG(Y1))*
     1  (ALOG(X)-ALOG(X1))/(ALOG(X2)-ALOG(X1)) + ALOG(Y1))
C
C
      J=2
C-------use lowest two data points for energies below table
      IF(EKEV.LT.E(1)) GO TO 212
 200  IF(EKEV - E(J)) 212,211,210
 210  J = J + 1
      IF(J.LT.26) GOTO 200
C-------use highest two data points for energies above table
      GOTO 212
 211  AMU =  MUORHO(J)
      RETURN
 212  CONTINUE
      AMU = LOGINT(EKEV,E(J-1),E(J),MUORHO(J-1),MUORHO(J))
      RETURN
      END
C-
      FUNCTION ROENTG(EKEV)
C%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
       REAL E(26), MUORHO(26), LOGINT
C-----Air mass absorption data from NSRDS-NBS 29, 1969 pg 20 & 21
      DATA E/10.,15.,20.,30.,40.,50.,60.,80.,100.,150.,200.,300.,
     1 400.,500.,600.,800.,1000.,1500.,2000.,3000.,4000.,5000.,
     2 6000.,8000.,10000.,15000./
      DATA MUORHO/ 4.61,1.28,0.511,0.148,0.0669,.0406,.0305,.0243,
     1 .0234,.0250,.0268,.0268,.0295,.0296,.0295,.0289,.0278,
     2 .0254,.0234,.0205,.0186,.0174,.0164,.0152,.0145,.0132/
C
C----USE LOG-LOG INTERPOLATION
      LOGINT(X,X1,X2,Y1,Y2) = EXP((ALOG(Y2)-ALOG(Y1))*
     1  (ALOG(X)-ALOG(X1))/(ALOG(X2)-ALOG(X1)) + ALOG(Y1))
C
C
      J=2
C-------use lowest two data points for energies below table
      IF(EKEV.LT.E(1)) GO TO 212
 200  IF(EKEV - E(J)) 212,211,210
 210  J = J + 1
      IF(J.LT.26) GOTO 200
C-------use highest two data points for energies above table
      GOTO 212
 211  ROENTG =  MUORHO(J) * EKEV * 244.3365 /1000.
      RETURN
 212  CONTINUE
      ROENTG = LOGINT(EKEV,E(J-1),E(J),MUORHO(J-1),MUORHO(J)) *
     1  EKEV * 244.3365 /1000.
      RETURN
      END
```

```
C-
      FUNCTION BUF(EKEV.MUR)
      REAL E(25), A1(25), A2(25), ALPHA1(25), ALPHA2(25), ALPHA3(25)
      REAL MUR, LOGINT, SEMINT
      COMMON /OLDJ/ EOLD, JOLD
      DATA E/15.,20.,30.,40.,50.,60.,80.,100.,150.,200.,300.,
     1 400.,500.,600.,800.,1000.,1500.,2000.,3000.,4000.,5000.,
     2 6000.,8000.,10000.,15000./
      DATA A1/1.259E1,4.960,1.039E1,1.183E2,5.106E2,
     1 1.641E3,1.477E3,1.503E3,1.242E3,1.206E3,
     2 1.251E3,1.182E3,1.232E3,4.316E3,1.102E3,
     3 1.128E3,2.941E2,4.159E2,1.162E2,1.928E1,
     4 1.251E1,1.047E1,1.011E1,8.889,6.661/
      DATA A2/-3.984E-1,-6.395E-1,-6.924E-1,-1.462E2,-6.189E2,
     1 -2.712E3,-2.543E3,-2.736E3,-2.317E3,-2.149E3,
     2 -1.756E3,-2.019E3,-1.664E3,-4.588E3,-1.308E3,
     3 -1.174E3,-2.179E2,-2.687E2,-6.740E1,-1.417E1,
     4 -6.071,-3.919,-3.046,-2.360,-1.496/
      DATA ALPHA1/-2.509E-2,-1.058E-?,-3.174E-2,-2.852E-2,-4.231E-2,
     1 -4.388E-2,-7.303E-2,-8.190E-2,-8.536E-2,-7.782E-2,
     2 -5.541E-2,-3.850E-2,-2.843E-2,-1.751E-2,-1.141E-2,
     3 -1.031E-2,-4.964E-2,-3.784E-2,-2.395E-2,-2.575E-2,
     4 -4.129E-2,-5.176E-2,-4.734E-2,-4.839E-2,-5.032E-2/
      DATA ALPHA2/3.955E-1,5.505E-1,9.030E-1,6.613E-3,-1.852E-2,
     1 -2.589E-2,-4.109E-2,-4.753E-2,-5.025E-2,-4.773E-2,
     2 -3.475E-2,-1.678E-2,-1.351E-2,-1.406E-2,-2.141E-3,
     3 -5.925E-3,-3.988E-2,-2.974E-2,-7.309E-3,2.054E-2.
     4 5.030E-2,7.394E-2,8.321E-2,9.146E-2,1.018E-1/
      DATA ALPHA3/-2.659E-2,3.524E-2,6.484E-2,6.739E-2,6.537E-2,
     1 6.546E-3,1.458E-3,-6.323E-3,-9.997E-3,-9.998E-3,
     2 1.528E-2,1.292E-2,2.686E-2,3.682E-2,4.240E-2,
     3 7.513E-2,-6.392E-2,-4.662E-2,-3.262E-2,-4.182E-2,
     4 -5.231E-2,-6.205E-2,-5.452E-2,-5.524E-2,-5.774E-2/
C***** BUILD UP FACTOR DATA FROM NUC SCI & END 78 PG74 1981
      BF(A,B,C,D,E,UR)= A*EXP(-C*UR)+B*EXP(-D*UR)+(1-A-B)*EXP(-E*UR)
C----USE LOG-LOG INTERPOLATION
      LOGINT(X,X1,X2,Y1,Y2) = EXP((ALOG(Y2)-ALOG(Y1))*
     1  (ALOG(X)-ALOG(X1))/(ALOG(X2)-ALOG(X1)) + ALOG(Y1))
      SEMINT(X.X1,X2,Y1,Y2) = EXP((ALOG(Y2)-ALOG(Y1))*
     1  (X-X1)/(X2-X1) + ALOG(Y1))
C***** DO NOT LOOK UP CONSTANTS IF YOU ARE NOT CHANGING ENERGY
      IF(EKEV.EQ.EOLD)THEN
      J = JOLD
      GOTO 212
      ENDIF
      EOLD = EKEV
C
      J=2
C-------use lowest two data points for energies below table
      IF(EKEV.LT.E(1)) GO TO 212
 200  IF(EKEV - E(J)) 212,211,210
```

```
 210  J = J + 1
      IF(J.LT.25) GOTO 200
C-------use highest two data points for energies above table
      GOTO 212
 211  IF(MUR.GT.40.) GOTO 213
      BUF = BF(A1(J),A2(J),ALPHA1(J),ALPHA2(J),ALPHA3(J),MUR)
C     WRITE(1,900)EKEV,BUF,J,A1(J),A2(J),ALPHA1(J),ALPHA2(J),ALPHA3(J)
      JOLD = J
      RETURN
 212  CONTINUE
      IF(MUR.GT.40.) GOTO 213
      X2=   BF(A1(J),A2(J),ALPHA1(J),ALPHA2(J),ALPHA3(J),MUR)
      X1=BF(A1(J-1),A2(J-1),ALPHA1(J-1),ALPHA2(J-1),ALPHA3(J-1),MUR)
      BUF = LOGINT(EKEV,E(J-1),E(J),X1,X2)
      JOLD = J
      RETURN
 213  CONTINUE
C-----IF MFPS ARE GT 40 INTERPRET FROM END OF RANGE
      X2=   BF(A1(J),A2(J),ALPHA1(J),ALPHA2(J),ALPHA3(J),40.)
      X1=BF(A1(J-1),A2(J-1),ALPHA1(J-1),ALPHA2(J-1),ALPHA3(J-1),40.)
      BUF2 = LOGINT(EKEV,E(J-1),E(J),X1,X2)
      X2=   BF(A1(J),A2(J),ALPHA1(J),ALPHA2(J),ALPHA3(J),35.)
      X1=BF(A1(J-1),A2(J-1),ALPHA1(J-1),ALPHA2(J-1),ALPHA3(J-1),35.)
      BUF1 = LOGINT(EKEV,E(J-1),E(J),X1,X2)
      BUF = SEMINT(MUR,35.,40.,BUF1,BUF2)
      JOLD = J
      RETURN
        END
C-
      FUNCTION BCONC(EKEV,RMFP)
C-----THIS FUNCTION CALCULATES THE BUILD UP FACTOR IN CONCRETE OR
C-----CONCRETE LIKE MATERIALS FROM THE NBS SOLUTION USING 12 PARAMETERS
C-----BY EISENHAUER AND SIMMONS REF NUC SCI AND ENG 56,263-270,1975
C
C----- R IS IN MFPS
C
      REAL E(25), DO(25),MUC(25),LOGINT,MUCONC
      REAL A0(25),A1(25),A2(25),A3(25),A4(25)
      REAL B0(25),B1(25),B2(25),B3(25),B4(25)
      REAL*8 BFC
      COMMON /OLDJ2/ EOLD2, JOLD2
      DATA E/15.,20.,30.,40.,50.,60.,80.,100.,150.,200.,300.,
     1 400.,500.,600.,800.,1000.,1500.,2000.,3000.,4000.,5000.,
     2 6000.,8000.,10000.,15000./
      DATA MUC/8.0100,3.4450,1.1180,0.5588,0.3608,0.2734,0.2004,0.1704,
     1 0.1399,0.1250,0.1073,0.0958,0.0873,0.0807,0.0709,
     2 0.0637,0.0519,0.0448,0.0365,0.0319,0.0290,0.0270,0.0245,
     3 0.0231,0.0215/
      DATA DO/0.1589,0.1487,0.1327,0.1200,0.1128,
     1 0.1118,0.1215,0.1376,0.1791,0.2149,0.2690,
     2 0.3088,0.3409,0.3674,0.4085,0.4404,0.4961,
```

```
3 0.5280,0.5679,0.5938,0.6158,0.6241,0.6425,0.6560,0.6676/
 DATA A0/1.1135E-2,2.4283E-2,0.06645,0.11734,0.15910,
1 0.18644,0.22372,0.24651,0.27760,0.29820,0.31837,
2 0.32929,0.33559,0.33965,0.34413,0.34678,0.35110,
3 0.35445,0.35691,0.35425,0.34788,0.33878,0.31686,
4 0.29369,0.24038/
 DATA A1/-0.0011583,-0.0024618,-0.0060622,-0.0092903,
1 -0.015356,+0.025044,-0.010144,0.040674,0.021783,
2 0.029893,0.012225,0.0095543,0.0044976,0.0073127,
3 0.0091422,0.0098983,0.010016,0.0099221,0.0078632,
4 0.010371,0.040628,0.030809,-0.013397,-0.016610,-0.0029308/
 DATA A2/5.483E-04,1.2409E-03,3.9089E-03,8.6343E-03,
1 1.5169E-02,1.1833E-02,3.7832E-02,3.2059E-02,2.9878E-02,
2 4.8446E-02,
3 5.5001E-02,5.0474E-02,2.2018E-02,2.7012E-02,2.2857E-02,
4 2.0876E-02,1.9785E-02,1.9206E-02,2.1801E-02,3.9089E-02,
5 -9.3940E-03,-8.8533E-03,2.8838E-02,2.7261E-02,-1.9101E-02/
 DATA A3/2.1503E-04,5.0984E-04,1.7224E-03,4.0328E-03,
1 7.5754E-03,1.3153E-03,3.0337E-02,2.6207E-02,3.1915E-02,
2 8.2357E-02,1.0486E-01,1.1029E-01,3.4039E-02,3.1744E-02,
3 4.4123E-02,5.0435E-02,5.2275E-02,4.9103E-02,3.9008E-02,
4 2.9853E-02,2.8888E-02,2.5995E-02,1.8330E-02,1.4079E-02,
5 2.2817E-02/
 DATA A4/ .2382E-05,1.0829E-04,3.9905E-04,1.0308E-03,
1 2.2527E-03,0.00000000,1.2457E-02,3.1514E-06,5.8041E-02,
2 -1.4608E-04,-8.6411E-04,-6.3551E-08,1.0539E-01,9.4382E-02,
3 7.3809E-02,5.9498E-02,4.0714E-02,3.2172E-02,2.2187E-02,
4 2.0070E-03,6.7348E-05,3.5701E-03,1.5406E-03,3.6397E-07,
5 9.8532E-03/
 DATA B0/0.57471,0.56384,0.54853,0.53850,0.53787,
1 0.54758,0.57172,0.60062,0.65913,0.69464,0.73934,
2 0.76455,0.78166,0.79363,0.80851,0.81671,0.82277,
3 0.81861,0.80467,0.79201,0.78176,0.77269,0.75988,
4 0.75116,0.73974/
 DATA B2/0.72706,0.71518,0.69814,0.68724,0.68395,
1 0.90637,0.69136,0.86298,0.77287,0.84634,0.82898,
2 0.82998,0.76467,0.79645,0.80369,0.80482,0.79882,
3 0.79546,0.81708,0.85749,0.72880,0.63341,0.85214,
4 0.86119,0.55119/
 DATA B1/0.42393,0.41368,0.39364,0.36010,0.28648,
1 0.70718,0.80330,0.69185,0.68532,0.71979,0.68807,
2 0.65925,0.56762,0.58849,0.57175,0.55269,0.52360,
3 0.50858,0.46877,0.30734,0.83930,0.83961,0.57962,
4 0.56105,0.85134/
 DATA B3/0.87317,0.86506,0.85649,0.85396,0.85703,
1 1.00436,0.85532,0.98931,0.87818,1.01431,1.01389,
2 1.00620,0.87305,0.90888,0.91929,0.91859,0.91265,
3 0.90861,0.91102,0.96145,0.96388,0.94894,0.95976,
4 0.97377,0.86292/
 DATA B4/0.96440,0.96154,0.95995,0.96110,0.96562,
1 1.00000,0.98034,1.17560,1.00645,1.09682,1.07209,
```

```
     2 1.34178,1.00139,0.99831,0.99455,0.99168,0.98767,
     3 0.98542,0.98436,1.01553,1.10390,1.09529,1.01101,
     4 1.22902,0.97741/
      BFC(R,U,A0,A1,A2,A3,A4,B0,B1,B2,B3,B4,D0) = 1 + (
     1 A0*U*R*DEXP(-DBLE(U*R/B0))+A1*(U*R/B1)**2*DEXP(-DBLE(U*R/B1))+
     2 A2 * (U*R/B2)**2 * DEXP(-DBLE(U*R/B2)) +
     3 A3 * (U*R/B3)**2 * DEXP(-DBLE(U*R/B3)) +
     4 A4*(U*R/B4)**2*DEXP(-DBLE(U*R/B4)))/(D0*DEXP(-DBLE(U*R)))
C----USE LOG-LOG INTERPOLATION
      LOGINT(X,X1,X2,Y1,Y2) = EXP((ALOG(Y2)-ALOG(Y1))*
     1  (ALOG(X)-ALOG(X1))/(ALOG(X2)-ALOG(X1)) + ALOG(Y1))
      R = RMFP / MUCONC(EKEV)
C                 WRITE(*,1000) 'BCONC  2',EKEV
C****** DO NOT LOOK UP CONSTANTS IF YOU ARE NOT CHANGING ENERGY
      IF(EKEV.EQ.EOLD2)THEN
      J = JOLD2
      GOTO 212
      ENDIF
      EOLD2 = EKEV
C
      J=2
C-------use lowest two data points for energies below table
      IF(EKEV.LT.E(1)) GO TO 212
 200  IF(EKEV - E(J)) 212,211,210
 210  J = J + 1
      IF(J.LT.25) GOTO 200
C-------use highest two data points for energies above table
      GOTO 212
 211  BCONC=BFC(R,MUC(J),A0(J),A1(J),A2(J),A3(J),A4(J),B0(J),B1(J),
     1 B2(J),B3(J),B4(J),D0(J))
      URCONC = R * MUC(J)
      JOLD2 = J
      RETURN
 212  CONTINUE
      X2=BFC(R,MUC(J),A0(J),A1(J),A2(J),A3(J),A4(J),B0(J),B1(J),B2(J),
     1 B3(J),B4(J),D0(J))
      K = J - 1
       X1=BFC(R,MUC(K),A0(K),A1(K),A2(K),A3(K),A4(K),B0(K),B1(K),B2(K),
     1 B3(K),B4(K),D0(K))
      BCONC = LOGINT(EKEV,E(J-1),E(J),X1,X2)
      URCONC = R * LOGINT(EKEV,E(J-1),E(J),MUC(J-1),MUC(J))
      JOLD2 = J
      RETURN
        END
C-
      REAL FUNCTION MUCONC(EKEV)
C-----this fucntion calculates mu over rho for concrete in cm2/gr
      REAL E(25), MUORHO(25), LOGINT
C-----mass attenuation data from Nuc Sci & Eng 56 pr 267, 1975
C
      DATA E/15.,20.,30.,40.,50.,60.,80.,100.,150.,200.,300.,
```

```
     1 400.,500.,600.,800.,1000.,1500.,2000.,3000.,4000.,5000.,
     2 6000.,8000.,10000.,15000./
      DATA MUORHO/8.0100,3.4450,1.1180,0.5588,0.3608,0.2734,0.2304,
     1 0.1704,0.1399,0.1250,0.1073,0.0958,0.0873,0.0807,0.0709,
     2 0.0637,0.0519,0.0448,0.0365,0.0319,0.0290,0.0270,0.0245,
     3 0.0231,0.0215/
C
C----USE LOG-LOG INTERPOLATION
      LOGINT(X,X1,X2,Y1,Y2) = EXP((ALOG(Y2)-ALOG(Y1))*
     1  (ALOG(X)-ALOG(X1))/(ALOG(X2)-ALOG(X1)) + ALOG(Y1))
C
      J=2
C-------use lowest two data points for energies below table
      IF(EKEV.LT.E(1)) GO TO 212
 200  IF(EKEV - E(J)) 212,211,210
 210  J = J + 1
      IF(J.LT.26) GOTO 200
C-------use highest two data points for energies above table
      GOTO 212
 211  MUCONC =  MUORHO(J)
      RETURN
 212  CONTINUE
      MUCONC = LOGINT(EKEV,E(J-1),E(J),MUORHO(J-1),MUORHO(J))
      RETURN
      END
```

APPENDIX C

CLOUD PROGRAM DESCRIPTION AND LISTING

The Cloud program calculates the DRFs for a cloud source when the detector is centered at ground level inside a structure. The program model is discussed in Section 2.8. Required input includes the equivalent radius of the structure, and the mass thickness of the walls.

When the Cloud program is run, it will ask for input data as shown in Figure 28. The first input required is a title and date for the output listing. The program then requires the equivalent radius to the inside of the assumed hemi-spherical structure, followed by the mass thickness of the wall. The program then asks the "Do you wish to specify a maximum cloud height?" followed by "Do you wish to specify a maximum cloud radius?". Normally the answer to both questions would be no (n). A yes (y) answer to either question would allow the study of the effects of limited cloud size on the exposures or DRFs (see Section 2.7). The program then calculates the resultant DRF's for the PWR-2 (RSS) cloud spectra, the 1-Hr bomb fallout spectra, and the TMI

```
B>cloud
INPUT TITLE/DATE OF OUTPUT
Small Wood House.  16 Sept 1984
INPUT RADIUS TO INSIDE OF HEMI-SPHERE IN METERS  5.
INPUT MASS THICHNESS OF WALL IN gr/cm**2          10.
DO YOU WISH TO SPECIFY A MAXIMUM CLOUD HEIGHT?, Y or N
y
Input MAXIMUM CLOUD HEIGHT in meters 1000.
DO YOU WISH TO SPECIFY A MAXIMUM CLOUD RADIUS?, Y or N
y
Input MAXIMUM CLOUD RADIUS in meters 1500.
```

FIGURE 28 Typical Computer CRT Display During Initiation of Cloud Program.

cloud spectra followed by the DRFs for energies from 15 KeV to 15 MeV. A typical output listing in shown in Table 15.

The program calculates the unprotected exposure in R per Curie of airborne radioactive material per cubic meter. The program then finds the protected exposure from the exterior cloud source, followed by the exposure from an interior cloud containing 1 Curie per cubic meter of radioactive material. The DRFs are calculated from the unprotected and protected exposures. The protected exposures are then compared to the protected exposure from a PWR-2 (RSS) cloud spectra. The last column of data is the exclusion factor discussed in Section 2.9.2. The program assumes one gamma per disintegration for the 1 Hr. bomb fallout, the PWR-2 cloud (RSS-Cloud) and the individual gamma energy calculations,.

The program is written in Microsoft FORTRAN 3.13. This is a version of FORTRAN 77. There are no non-standard FORTRAN commands in the program. The program was run on a Texas Instruments Professional Computer (PC) which uses an 8088 processor and an 8087 co-processor. The program was run under the MS-DOS 2.11 operating system. However, it should run on any computer capable of using FORTRAN 77. The program takes approximately 25 minutes running time. Caution, the program is written is FORTRAN, the input requires decimal points. The program may not converge to an

answer for low energies (15 and 20 KeV) for wall thickness greater than about 20 gr/cm^2. This is because the exposures are less than 8.43E-37, which is the limit of the single precision data type used for real variables.

The MAIN program directs the input and output of the program data. Subroutine SIMPS carries out the integrations by using Simpson's rule. The number of increments is automatically increased until the desired accuracy is obtained. Subroutine PROTECT speeds the integration of the hemi-spherical source by dividing the source into shells which converge to integrals faster. Function DHEMI finds the kernel for the unprotected cloud source. Function DSPHER calculates the kernel for the protected cloud source.

Function AMU finds the mass attenuation coefficient for air. Function BUF finds the buildup factor for air. Function MUCONC finds the mass attenuation coefficient for the walls. Function BCONC finds the buildup factor for the walls. Function ROENTG finds the factor for converting flux to exposure.

The listing of the Cloud program follows.

```
      PROGRAM CLOUD
      CHARACTER CTITLE*80,YORN*1
      INTEGER IN, OUT
      REAL E(23)
      REAL HMAX,RMAX,EGROUP(20,4),FRACT(20,4)
      EXTERNAL F, DHEMI,DSPHER
      COMMON /ENERGY/EKEV
      COMMON /SIZE/ WALLDS,WTHICK,RMAX,HMAX,R1
      COMMON /EXPOS/ TOTEXP,TOTUNP,EXPOSE
      COMMON /INOUT/ IN, OUT
      COMMON /OLDJ/ EOLD, JOLD
      COMMON /OLDJ2/ EOLD2, JOLD2
      DATA E/15.,20.,30.,40.,50.,60.,80.,100.,150.,200.,300.,
     1 420.,500.,600.,662.,800.,1000.,1173.,1332.,1500.,
     2 2000.,3000.,4000.,5000.,6000.,8000.,10000.,15000./
      DATA EGROUP /50.,300.,750.,1500.,2500.,15*0.,
     1 25.,75.,150.,250.,350.,500.,700.,900.,1165.,
     2 1500.,1830.,2250.,2750.,3500.,4500.,5*0.,
     3 2630.,2400.,2190.,1863.,1550.,898.,850.,
     4 610.,527.,360.,250.,233.,191.,166.,81.,28.,4*0.,
     5 81.,164.,284.,364.,637.,662.,723.,13*0./
      DATA FRACT /.3693,.3059,.1476,.1041,.0732,15*0.,
     1 .0271,.0137,.0737,.0476,.0929,.1373,.1717,.1627,
     2 .2889,.0957,.0299,.0397,.0148,.0042,.0001,5*0.,
     3 .000239,.00319,.00164,.00191,.00127,
     4 .00118,.00209,.00732,.0168,.000454,
     5 .2220,.00252,.00319,.00637,.2764,.000637,4*0.,
     6 .3696,.00002,.000054,.000819,.000068,.000042,.000016,13*0./
C*********************************************************************
C***************INPUT TITLE FOR EACH LISTING***********************
 807  FORMAT(1H0,25X,'CLOUD SOURCE WITH WALL WRITTEN 22 JUNE 1984')
C*********************************************************************
C+++++CHANGE EPSON FX-80 PRINTER TO COMPRESS MODE
      OPEN (1,FILE='LPT1',STATUS='NEW',ACCESS='DIRECT'
     1 ,FORM='UNFORMATTED',RECL=1)
      WRITE (1)27,15
      CLOSE (1)
      OPEN(1,FILE='LPT1')
C
      OUT = 1
      EOLD = 0.0
      EOLD2 = 0.0
      IN = 0
      WALLDS = .2
C-----Assume walls and roof are .2 meters thick.
C%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
      WRITE(*,290)
 290  FORMAT(1X,'INPUT TITLE/DATE OF OUTPUT')
      READ(*,291)CTITLE
 291  FORMAT(A80)
 292  FORMAT(1H0,25X,A80)
```

```
C%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
 300  WRITE(*,301)
 301  FORMAT(1X,'INPUT RADIUS TO INSIDE OF HEMI-SPHERE IN METERS   ',\)
 302  READ (*,303) R1
 303  FORMAT(F13.6)
      WRITE(*,304)
 304  FORMAT(1X,'INPUT MASS THICHNESS OF WALL IN gr/cm**2             ',\)
      READ (*,303) WTHICK
 293  WRITE(*,294)
 294  FORMAT(1X,
     1 'DO YOU WISH TO SPECIFY A MAXIMUM CLOUD HEIGHT?, Y or N')
      READ(*,295)YORN
 295  FORMAT(A1)
            IF(YORN.EQ.'Y'.OR.YORN.EQ.'y') THEN
             WRITE(*,296)
 296         FORMAT(1X,'Input MAXIMUM CLOUD HEIGHT in meters ',\)
             READ(*,303)HMAX
            ELSEIF(YORN.EQ.'N'.OR.YORN.EQ.'n')THEN
             HMAX = 1E+30
            ELSE
             GOTO 293
            ENDIF
 297  WRITE(*,298)
 298  FORMAT(1X,
     1 'DO YOU WISH TO SPECIFY A MAXIMUM CLOUD RADIUS?, Y or N')
      READ(*,295)YORN
            IF(YORN.EQ.'Y'.OR.YORN.EQ.'y') THEN
             WRITE(*,299)
 299         FORMAT(1X,'Input MAXIMUM CLOUD RADIUS in meters ',\)
             READ(*,303)RMAX
            ELSEIF(YORN.EQ.'N'.OR.YORN.EQ.'n') THEN
             RMAX = 1E+30
            ELSE
             GOTO 297
            ENDIF
      WRITE(OUT,807)
      WRITE(OUT,292)CTITLE
      WRITE(OUT,808)
      WRITE(OUT,809) R1
      WRITE(OUT,813) WTHICK
      WRITE(OUT,811) HMAX
      WRITE(OUT,812) RMAX
      WRITE(OUT,803)
      WRITE(OUT,804)
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
C@@@@@ ROUTINE TO FIND DRFS FOR SPECTRA
      DO 500 NSPEC = 1,3,+1
      DOSUNP = 0.
      DOSCLD = 0.
      DOSINT = 0.
      DO 501 IEKEV = 1,20
```

```
      EKEV = EGROUP(IEKEV,NSPEC)
      FRCT = FRACT(IEKEV,NSPEC)
      IF(FRCT.EQ.0) GOTO 501
      WRITE(*,806) EKEV
C-----LET YOU KNOW PROGRAM IS RUNNING
      CALL PROTECT(EKEV)
      CALL SIMPS(0.,R1,1.E-5,DINT,DHEMI)
      DOSUNP = DOSUNP + FRCT  * TOTUNP
      DOSCLD = DOSCLD + FRCT * TOTEXP
      DOSINT = DOSINT + DINT * EXPOSE * FRCT
 501  CONTINUE
      DRF = DOSCLD/DOSUNP
      IF(NSPEC.EQ.1) DRF3MB = DRF
      RATIO = DRF/DRF3MB
      EXCLUDE = DOSCLD/(DOSCLD + DOSINT)
      IF(NSPEC.EQ.2)WRITE(OUT,505)DOSUNP,DOSCLD,DOSINT,
     1 DRF,RATIO,EXCLUDE
      IF(NSPEC.EQ.1)WRITE(OUT,510)DOSUNP,DOSCLD,DOSINT,
     1 DRF,RATIO,EXCLUDE
      IF(NSPEC.EQ.3)WRITE(OUT,506)DOSUNP,DOSCLD,DOSINT,
     1 DRF,RATIO,EXCLUDE
      IF(NSPEC.EQ.4)WRITE(OUT,507)DOSUNP,DOSCLD,DOSINT,
     1 DRF,RATIO,EXCLUDE
 500  CONTINUE
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
C@@@@@ routine for genertating energy table @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
         DO 801 IEKEV = 28,1,-1
       EKEV = E(IEKEV)
      WRITE(*,806) EKEV
 806  FORMAT(1X,'E(KeV) = ',G10.5,\)
C-----LET YOU KNOW PROGRAM IS RUNNING
      DOSUNP = 0.
      DOSCLD = 0.
      DOSINT = 0.
      CALL PROTECT(EKEV)
      CALL SIMPS(0.,R1,1.E-5,DINT,DHEMI)
      DOSUNP = DOSUNP + TOTUNP
      DOSCLD = DOSCLD + TOTEXP
      DOSINT = DOSINT + DINT * EXPOSE
      DRF = DOSCLD/DOSUNP
        RATIO = DRF/DRF3MB
      EXCLUDE = DOSCLD/(DOSCLD + DOSINT)
        ERRLIM = 1.E-30
      IF(DOSUNP.GT.ERRLIM) THEN
        DRF = DOSCLD/DOSUNP
      ELSE
        DRF = 0.
      ENDIF
      ONEMEX = 1. - EXCLUD
      WRITE(OUT,802) EKEV,DOSUNP,DOSCLD,DOSINT
     1 ,DRF,RATIO,EXCLUDE
```

```
801        CONTINUE
800   CONTINUE
802   FORMAT(1X,25X,F7.1,4X,6(G10.4,4X))
803   FORMAT(1H0,25X,'E(KeV)',5X,
     1 'R/hr/Ci*m3',4X,'R/hr/Ci*m3',4X,'R/hr/Ci*m3',4x,
     2 ' DRF ',9X,'R/R(RSS)',6X,
     3 'Exclusion')
804   FORMAT(1X,25X,12X,'Unprotected',3X,'Protected',5x,
     1 'from int.',5X,14X,14X,'Factor')
808   FORMAT(1H0,25X,'Integration to 12 MFPs in air.')
809   FORMAT(1X,25X,'Equivalent radius of structure = ',F9.3,' meters')
813   FORMAT(1X,25X,'Mass thickness of walls = ',F9.3,' gr/cm**2')
811   FORMAT(1X,25X,'Maximum cloud height = ',F12.3,' meters')
812   FORMAT(1X,25X,'Maximum cloud radius = ',F12.3,' meters')
505   FORMAT(1X,25X,'1.12 HR. ',2X,6(G10.4,4X))
513   FORMAT(1X,25X,'RSS-CLOUD',2X,6(G10.4,4X))
506   FORMAT(1X,25X,'TMI-CLOUD',2X,6(G10.4,4X))
507   FORMAT(1X,25X,'SL1-CLOUD',2X,6(G10.4,4X))
     STOP
      END
C
      SUBROUTINE PROTECT(EKEV)
      REAL TOLER(10),DMFP(10),KERN,MFP
        EXTERNAL DHEMI,DSPHER
      COMMON /SIZE/ WALLDS,WTHICK,RMAX,HMAX,R1
      COMMON /EXPOS/ TOTEXP,TOTUNP,EXPOSE
      DATA  TOLER/1.E-4,1.E-4,1.E-4,1.E-4,1.E-4,1.E-4,
     1  1.E-4,1.E-4,1.E-3,1.E-2/
      DATA DMFP/.003,.01,.05,.1,.2,.5,1.,3.,5.,12./
C-----RHO = DENSITY OF AIR AT STP 0.001293 gm/cm**3
      RHO = 0.001293
       AMUEKEV = AMU(EKEV)
       MFP = AMUEKEV * RHO *100.
       EXPOSE = ROENTG(EKEV)
C-----DISTANCES ARE IN METERS, MU IN INVERSE CENTIMETERS, XJ IS IN MFPS
      TOTEXP = 0.
      TOTUNP = 0.
      N1=0
      N2=0
      DO 805 J = 1,10
      XJ = DMFP(J)
      TOL = TOLER(J)
C***** IF R1 IS GREATER THAN XJ DO NOT INTEGRATE BACKWARDS
      XJM1 = (R1 + WALLDS) * MFP
      IF(XJ.LE.XJM1) GOTO 805
      N1 = N1 + 1
      D2 = XJ/MFP
            IF(D2.GT.RMAX) THEN
                  D2 = RMAX
                  N2 = N2 + 1
            ENDIF
```

```
                IF(N1.EQ.1) THEN
                 XXJM1 = XJM1
                 X2JM1 = 0.
                ELSE
                 XJM1 = DMFP(J-1)
                 X2JM1 = DMFP(J-1)
                END IF
      D1 = XJM1/MFP
      D21 = X2JM1/MFP
      D22 = D2
        CALL SIMPS(D1,D2,TOL,KERN,DSPHER)
        CALL SIMPS(D21,D22,TOL,UNSHLD,DHEMI)
      TOTEXP = TOTEXP + EXPOSE * KERN
      TOTUNP = TOTUNP + EXPOSE * UNSHLD
 905    CONTINUE
      RETURN
      END
C
      SUBROUTINE SIMPS(LOWER, UPPER, TOL, SUM, F)
C*****************************************************
C NUMERICAL INTEGRATION BY SIMPSON'S RULE.
      INTEGER IN, OUT, PIECES, I, P2
      REAL X, DELTA, LOWER, UPPER, SUM, TOL
      REAL ENDSUM, ODDSUM, SUM1, EVSUM
      COMMON /INOUT/ IN, OUT
C
      PIECES = 2
      DELTA = (UPPER - LOWER) / PIECES
      ODDSUM = F(LOWER + DELTA)
      EVSUM = 0.0
      ENDSUM = F(LOWER) + F(UPPER)
      SUM = (ENDSUM + 4 * ODDSUM) * DELTA / 3.0
 5    PIECES = PIECES + 2
            P2 = PIECES / 2
            SUM1 = SUM
            DELTA = (UPPER - LOWER) / PIECES
            EVSUM = EVSUM + ODDSUM
            ODDSUM = 0.0
            DO 10 I = 1, P2
            X = LOWER + DELTA * (2 * I - 1)
            ODDSUM = ODDSUM + F(X)
 10   CONTINUE
      SUM = (ENDSUM + 4.0 *ODDSUM + 2.0 * EVSUM)
     *       * DELTA / 3.0
      IF(ABS(SUM - SUM1) .GT. ABS(TOL * SUM)) GOTO 5
      RETURN
      END
C
      FUNCTION DHEMI(R)
C******** POINT KERNAL FOR A DISK SOURCE
      REAL MFP
```

```
      COMMON /ENERGY/ EKEV
      COMMON /SIZE/ WALLDS,T,RMAX,HMAX,R1
      MFP = AMU(EKEV) * 0.001293 * 100. * R
      BU = BUF(EKEV, MFP)
      SA = 1.
      DHEMI = .5*BU*SA*EXP(-MFP)
      IF(R.GT.HMAX) DHEMI = DHEMI * HMAX/R
      RETURN
      END
C
      FUNCTION AMU(EKEV)
C MASS ATTENUATION IN cm*2/gr
      REAL E(26), MUORHO(26), LOGINT
C-----AIR MASS ATTENUATION DATA FROM RADIOLOGICAL HEALTH HANDBOOK
C-----, JAN 1970, PG139
C
      DATA E/10.,15.,20.,30.,40.,50.,60.,80.,100.,150.,200.,300.,
     1 400.,500.,600.,800.,1000.,1500.,2000.,3000.,4000.,5000.,
     2 6000.,8000.,10000.,15000./
      DATA MUORHO/ 4.99 1.55,0.752,0.349,0.248,0.208,0.188,0.167,0.154,
     1 0.136,0.123,0.107,0.0954,0.0870,0.0805,0.0707,0.0636,
     2 0.0518,0.0445,0.0358,0.0308,0.0275,0.0252,0.0223,
     3 0.0204,0.0181/
C
C----USE LOG-LOG INTERPOLATION
C*****LININT(X,X1,X2,Y1,Y2) = (Y2-Y1)*(X-X1)/(X2-X1) + Y1
      LOGINT(X,X1,X2,Y1,Y2) = EXP((ALOG(Y2)-ALOG(Y1))*
     1  (ALOG(X)-ALOG(X1))/(ALOG(X2)-ALOG(X1)) + ALOG(Y1))
C
C
      J=2
C--------use lowest two data points for energies below table
      IF(EKEV.LT.E(1)) GO TO 212
 200  IF(EKEV - E(J)) 212,211,210
 210  J = J + 1
      IF(J.LT.26) GOTO 200
C--------use highest two data points for energies above table
      GOTO 212
 211  AMU =  MUORHO(J)
      RETURN
 212  CONTINUE
      AMU = LOGINT(EKEV,E(J-1),E(J),MUORHO(J-1),MUORHO(J))
      RETURN
      END
C
      FUNCTION DSPHER(R)
C********* POINT KERNAL FOR A SHERICAL SOURCE
      REAL MUAIR,MFP1,MFP2,MFP3,MUCONC,MFP
       INTEGER IN, OUT
      COMMON /ENERGY/ EKEV
      COMMON /SIZE/ WALLDS,T,RMAX,HMAX,R1
```

```
      COMMON /INOUT/ IN, OUT
C-----ASSUME ROOF IS .2 METERS THICK
      MUAIR = AMU(EKEV) * 0.001293
      MFP1 = (R -R1 - WALLDS) * MUAIR * 100.
      MFP2 =  T * MUCONC(EKEV)
      MFP3 =  R1 * MUAIR * 100.
      MFP = MFP1 + MFP2 + MFP3
      B1 = BUF(EKEV,MFP1)
      B2 = BCONC(EKEV,MFP1+MFP2)/BCONC(EKEV,MFP1)
      B3 = BUF(EKEV,MFP1+MFP2+MFP3)/BUF(EKEV,MFP1+MFP2)
      BU = B1*B2*B3
      SA = 1.
      IF((MFP2.GT.40.).OR.(MFP1+MFP3.GT.40.)) THEN
            DSPHER = 0.
            RETURN
            ELSE
      DSPHER=.5*BU*SA*EXP(-MFP)
            ENDIF
      IF(R.GT.HMAX)DSPHER = DSPHER * HMAX/R
      RETURN
      END
C
      FUNCTION ROENTG(EKEV)
C%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
C     This function converts BUF adjusted flux to R*m**2/hr/Ci
C%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
      REAL E(26), MUORHO(26), LOGINT
C-----Air mass absorption data from NSRDS-NBS 29, 1969 pg 20 & 21
      DATA E/10.,15.,20.,30.,40.,50.,60.,80.,100.,150.,200.,300.,
     1 400.,500.,600.,800.,1000.,1500.,2000.,3000.,4000.,5000.,
     2 6000.,8000.,10000.,15000./
      DATA MUORHO/ 4.61,1.28,0.511,0.148,0.0669,.0406,.0305,.0243,
     1 .0234,.0250,.0268,.0288,.0295,.0296,.0295,.0289,.0278,
     2 .0254,.0234,.0205,.0186,.0174,.0164,.0152,.0145,.0132/
C
C----USE LOG-LOG INTERPOLATION
      LOGINT(X,X1,X2,Y1,Y2) = EXP((ALOG(Y2)-ALOG(Y1))*
     1  (ALOG(X)-ALOG(X1))/(ALOG(X2)-ALOG(X1)) + ALOG(Y1))
C
      J=2
C-------use lowest two data points for energies below table
      IF(EKEV.LT.E(1)) GO TO 212
 200  IF(EKEV - E(J)) 212,211,210
 210  J = J + 1
      IF(J.LT.26) GOTO 200
C-------use highest two data points for energies above table
      GOTO 212
 211  ROENTG =  MUORHO(J) * EKEV * 244.3365 /1000.
      RETURN
 212  CONTINUE
      ROENTG = LOGINT(EKEV,E(J-1),E(J),MUORHO(J-1),MUORHO(J)) *
```

```
     1  EKEV * 244.3365 /1000.
      RETURN
      END
C
      FUNCTION BUF(EKEV,MUR)
      REAL E(25), A1(25), A2(25), ALPHA1(25), ALPHA2(25), ALPHA3(25)
      REAL MUR, LOGINT, SEMINT
      COMMON /OLDJ/ EOLD, JOLD
      DATA E/15.,20.,30.,40.,50.,60.,80.,100.,150.,200.,300.,
     1 400.,500.,600.,800.,1000.,1500.,2000.,3000.,4000.,5000.,
     2 6000.,8000.,10000.,15000./
      DATA A1/1.258E1,4.960,1.039E1,1.183E2,5.106E2,
     1 1.641E3,1.477E3,1.503E3,1.242E3,1.206E3,
     2 1.251E3,1.182E3,1.232E3,4.316E3,1.102E3,
     3 1.128E3,2.941E2,4.159E2,1.162E2,1.928E1,
     4 1.251E1,1.047E1,1.011E1,8.889,6.661/
      DATA A2/-3.984E-1,-6.395E-1,-6.924E-1,-1.462E2,-6.189E2,
     1 -2.712E3,-2.543E3,-2.736E3,-2.317E3,-2.149E3,
     2 -1.756E3,-2.019E3,-1.664E3,-4.588E3,-1.308E3,
     3 -1.174E3,-2.179E2,-2.687E2,-6.740E1,-1.417E1,
     4 -6.071,-3.919,-3.046,-2.360,-1.496/
      DATA ALPHA1/-2.509E-2,-1.058E-3,-3.174E-2,-2.852E-2,-4.231E-2,
     1 -4.888E-2,-7.303E-2,-8.190E-2,-8.536E-2,-7.785E-2,
     2 -5.541E-2,-3.850E-2,-2.843E-2,-1.751E-2,-1.141E-2,
     3 -1.031E-2,-4.964E-2,-3.784E-2,-2.395E-2,-2.575E-2,
     4 -4.129E-2,-5.176E-2,-4.734E-2,-4.839E-2,-5.032E-2/
      DATA ALPHA2/3.955E-1,5.505E-1,9.030E-1,6.613E-3,-1.852E-2,
     1 -2.589E-2,-4.109E-2,-4.753E-2,-5.025E-2,-4.773E-2,
     2 -3.475E-2,-1.678E-2,-1.351E-2,-1.406E-2,-2.141E-3,
     3 -5.925E-3,-3.988E-2,-2.974E-2,-7.309E-3,2.054E-2,
     4 5.030E-2,7.394E-2,8.321E-2,9.146E-2,1.018E-1/
      DATA ALPHA3/-2.659E-2,3.524E-2,6.484E-2,6.739E-2,6.537E-2,
     1 6.546E-3,1.458E-3,-6.323E-3,-9.997E-3,-9.998E-3,
     2 1.528E-2,1.292E-2,2.686E-2,3.682E-2,4.240E-2,
     3 7.813E-2,-6.392E-2,-4.662E-2,-3.262E-2,-4.182E-2,
     4 -5.231E-2,-6.205E-2,-5.452E-2,-5.524E-2,-5.774E-2/
C***** BUILD UP FACTOR DATA FROM NUC SCI & END 78 PG74 1981
      BF(A,B,C,D,E,UR)= A*EXP(-C*UR)+B*EXP(-D*UR)+(1-A-B)*EXP(-E*UR)
C----USE LOG-LOG INTERPOLATION
      LOGINT(X,X1,X2,Y1,Y2) = EXP((ALOG(Y2)-ALOG(Y1))*
     1  (ALOG(X)-ALOG(X1))/(ALOG(X2)-ALOG(X1)) + ALOG(Y1))
      SEMINT(X,X1,X2,Y1,Y2) = EXP((ALOG(Y2)-ALOG(Y1))*
     1  (X-X1)/(X2-X1) + ALOG(Y1))
C***** DO NOT LOOK UP CONSTANTS IF YOU ARE NOT CHANGING ENERGY
      IF(EKEV.EQ.EOLD)THEN
      J = JOLD
      GOTO 212
      ENDIF
      EOLD = EKEV
C
      J=2
```

```
C-------use lowest two data points for energies below table
      IF(EKEV.LT.E(1)) GO TO 212
 200  IF(EKEV - E(J)) 212,211,210
 210  J = J + 1
      IF(J.LT.25) GOTO 200
C-------use highest two data points for energies above table
      GOTO 212
 211  IF(MUR.GT.40.) GOTO 213
      BUF = BF(A1(J),A2(J),ALPHA1(J),ALPHA2(J),ALPHA3(J),MUR)
C     WRITE(1,900)EKEV,BUF,J,A1(J),A2(J),ALPHA1(J),ALPHA2(J),ALPHA3(J)
      JOLD = J
      RETURN
 212  CONTINUE
      IF(MUR.GT.40.) GOTO 213
      X2=   BF(A1(J),A2(J),ALPHA1(J),ALPHA2(J),ALPHA3(J),MUR)
      X1=BF(A1(J-1),A2(J-1),ALPHA1(J-1),ALPHA2(J-1),ALPHA3(J-1),MUR)
      BUF = LOGINT(EKEV,E(J-1),E(J),X1,X2)
      JOLD = J
      RETURN
 213  CONTINUE
C-----IF MFPS ARE GT 40 INTERPRET FROM END OF RANGE
      X2=   BF(A1(J),A2(J),ALPHA1(J),ALPHA2(J),ALPHA3(J),40.)
      X1=BF(A1(J-1),A2(J-1),ALPHA1(J-1),ALPHA2(J-1),ALPHA3(J-1),40.)
      BUF2 = LOGINT(EKEV,E(J-1),E(J),X1,X2)
      X2=   BF(A1(J),A2(J),ALPHA1(J),ALPHA2(J),ALPHA3(J),35.)
      X1=BF(A1(J-1),A2(J-1),ALPHA1(J-1),ALPHA2(J-1),ALPHA3(J-1),35.)
      BUF1 = LOGINT(EKEV,E(J-1),E(J),X1,X2)
      BUF = SEMINT(MUR,35.,40.,BUF1,BUF2)
      JOLD = J
      RETURN
        END
C
C
      FUNCTION BCONC(EKEV,RMFP)
C-----THIS FUNCTION CALCULATES THE BUILD UP FACTOR IN CONCRETE OR
C-----CONCRETE LIKE MATERIALS FROM THE NBS SOLUTION USING 12 PARAMETERS
C-----BY EISENHAUER AND SIMMONS REF NUC SCI AND ENG 56,263-270,1975
C
C----- R IS IN MFPS
C
      REAL E(25), DD(25),MUC(25),LOGINT,MUCONC
      REAL A0(25),A1(25),A2(25),A3(25),A4(25)
      REAL B0(25),B1(25),B2(25),B3(25),B4(25)
      REAL*8 BFC
      COMMON /OLDJ2/ EOLD2, JOLD2
      DATA E/15.,20.,30.,40.,50.,60.,80.,100.,150.,200.,300.,
     1 400.,500.,600.,800.,1000.,1500.,2000.,3000.,4000.,5000.,
     2 6000.,8000.,10000.,15000./
      DATA MUC/8.0100,3.4450,1.1180,0.5588,0.3608,0.2734,0.2004,0.1704,
     1 0.1399,0.1250,0.1073,0.0958,0.0873,0.0807,0.0709,
     2 0.0637,0.0519,0.0448,0.0365,0.0319,0.0290,0.0270,0.0245,
```

```
3 0.0231,0.0215/
 DATA D0/0.1589,0.1487,0.1327,0.1200,0.1128,
1 0.1118,0.1215,0.1376,0.1791,0.2149,0.2690,
2 0.3088,0.3409,0.3674,0.4085,0.4404,0.4961,
3 0.5280,0.5679,0.5938,0.6158,0.6241,0.6425,0.6560,0.6676/
 DATA A0/1.1135E-2,2.4283E-2,0.06645,0.11734,0.15910,
1 0.18644,0.22372,0.24651,0.27760,0.29820,0.31837,
2 0.32929,0.33559,0.33965,0.34413,0.34678,0.35110,
3 0.35445,0.35691,0.35425,0.34788,0.33878,0.31686,
4 0.29369,0.24038/
 DATA A1/-0.0011583,-0.0024618,-0.0060622,-0.0092903,
1 -0.015356,+0.025044,-0.010144,0.040674,0.021783,
2 0.029893,0.012225,0.0095543,0.0044976,0.0073127,
3 0.0091422,0.0098983,0.010016,0.0099221,0.0078632,
4 0.010371,0.040628,0.030809,-0.013397,-0.016610,-0.0029308/
 DATA A2/5.483E-04,1.2409E-03,3.9089E-03,8.6343E-03,
1 1.5169E-02,1.1833E-02,3.7832E-02,3.2059E-02,2.9878E-02,
2 4.8446E-02,
3 5.5001E-02,5.0474E-02,2.2018E-02,2.7012E-02,2.2857E-02,
4 2.0876E-02,1.9785E-02,1.9206E-02,2.1801E-02,3.9089E-02,
5 -9.3940E-03,-8.8533E-03,2.8838E-02,2.7261E-02,-1.9101E-02/
 DATA A3/2.1503E-04,5.0984E-04,1.7224E-03,4.0328E-03,
1 7.5754E-03,1.3153E-03,3.0337E-02,2.6207E-02,3.1915E-02,
2 8.2357E-02,1.0486E-01,1.1029E-01,3.4039E-02,3.1744E-02,
3 4.4123E-02,5.0435E-02,5.2275E-02,4.9103E-02,3.9008E-02,
4 2.9853E-02,2.8888E-02,2.5095E-02,1.8330E-02,1.4079E-02,
5 2.2817E-02/
 DATA A4/4.2382E-05,1.0829E-04,3.9905E-04,1.0308E-03,
1 2.2527E-03,0.00000000,1.2457E-02,3.1514E-06,5.8041E-02,
2 -1.4608E-04,-8.6411E-04,-6.3551E-08,1.0539E-01,9.4382E-02,
3 7.3809E-02,5.9498E-02,4.0714E-02,3.2172E-02,2.2187E-02,
4 2.0070E-03,6.7348E-05,3.5701E-03,1.5406E-03,3.6397E-07,
5 9.8532E-03/
 DATA B0/0.57471,0.56384,0.54853,0.53850,0.53787,
1 0.54758,0.57172,0.60062,0.65913,0.69464,0.73934,
2 0.76455,0.78166,0.79363,0.80851,0.81671,0.82277,
3 0.81861,0.80467.0.79201,0.78176,0.77269,0.75988,
4 0.75116,0.73974/
 DATA B2/0.72706,0.71518,0.69814,0.68724,0.68395,
1 0.90637,0.69136,0.86298,0.77287,0.84634,0.82898,
2 0.82998,0.76467,0.79645,0.80369,0.80482,0.79982,
3 0.79546,0.81708,0.85749,0.72880,0.63341,0.85214,
4 0.86119,0.55119/
 DATA B1/0.42393,0.41368,0.39364,0.36010,0.28648,
1 0.70718,0.80330,0.69185,0.68532,0.71979,0.68807,
2 0.65925,0.56762,0.58849,0.57175,0.55269,0.52360,
3 0.50858,0.46877,0.30734,0.83930,0.83961,0.57962,
4 0.56105,0.85134/
 DATA B3/0.87317,0.86506,0.85649,0.85396,0.85703,
1 1.00436,0.85532,0.98931,0.87818,1.01431,1.01389,
2 1.00620,0.87305,0.90888,0.91929,0.91859,0.91265,
```

```
      3 0.90861,0.91102,0.96145,0.96388,0.94894,0.95976,
      4 0.97377,0.86292/
       DATA B4/0.96440,0.96154,0.95995,0.96110,0.96562,
      1 1.00000,0.98034,1.17560,1.00645,1.09682,1.07209,
      2 1.34178,1.00139,0.99831,0.99455,0.99160,0.98767,
      3 0.98542,0.98406,1.21558,1.10093,1.00529,1.01101,
      4 1.22902,0.97741/
       BFC(R,U,A0,A1,A2,A3,A4,B0,B1,B2,B3,B4,D0) = 1 + (
      1 A0*U*R*DEXP(-DBLE(U*R/B0))+A1*(U*R/B1)**2*DEXP(-DBLE(U*R/B1))+
      2 A2 * (U*R/B2)**2 * DEXP(-DBLE(U*R/B2)) +
      3 A3 * (U*R/B3)**2 * DEXP(-DBLE(U*R/B3)) +
      4 A4*(U*R/B4)**2*DEXP(-DBLE(U*R/B4)))/(D0*DEXP(-DBLE(U*R)))
C----USE LOG-LOG INTERPOLATION
       LOGINT(X,X1,X2,Y1,Y2) = EXP((ALOG(Y2)-ALOG(Y1))*
      1  (ALOG(X)-ALOG(X1))/(ALOG(X2)-ALOG(X1)) + ALOG(Y1))
       R = RMFP / MUCONC(EKEV)
C                 WRITE(*,1000) 'BCONC  2',EKEV
C****** DO NOT LOOK UP CONSTANTS IF YOU ARE NOT CHANGING ENERGY
       IF(EKEV.EQ.EOLD2)THEN
       J = JOLD2
       GOTO 212
       ENDIF
       EOLD2 = EKEV
C
       J=2
C-------use lowest two data points for energies below table
       IF(EKEV.LT.E(1)) GO TO 212
 200   IF(EKEV - E(J)) 212,211,210
 210   J = J + 1
       IF(J.LT.25) GOTO 200
C-------use highest two data points for energies above table
       GOTO 212
 211   BCONC=BFC(R,MUC(J),A0(J),A1(J),A2(J),A3(J),A4(J),B0(J),B1(J),
      1 B2(J),B3(J),B4(J),D0(J))
       URCONC = R * MUC(J)
       JOLD2 = J
       RETURN
 212   CONTINUE
       X2=BFC(R,MUC(J),A0(J),A1(J),A2(J),A3(J),A4(J),B0(J),B1(J),B2(J),
      1 B3(J),B4(J),D0(J))
       K = J - 1
        X1=BFC(R,MUC(K),A0(K),A1(K),A2(K),A3(K),A4(K),B0(K),B1(K),B2(K),
      1 B3(K),B4(K),D0(K))
       BCONC = LOGINT(EKEV,E(J-1),E(J),X1,X2)
       URCONC = R * LOGINT(EKEV,E(J-1),E(J),MUC(J-1),MUC(J))
       JOLD2 = J
       RETURN
         END
C
       REAL FUNCTION MUCONC(EKEV)
C-----this fucntion calculates mu over rho for concrete in cm2/gr
```

```
      REAL E(25), MUORHO(25), LOGINT
C-----mass attenuation data from Nuc Sci & Eng 56 pr 267, 1975
C
      DATA E/15.,20.,30.,40.,50.,60. 80.,100.,150.,200.,300.,
     1 400.,500.,600.,800.,1000.,1500.,2000.,3000.,4000.,5000.,
     2 6000.,8000.,10000.,15000./
      DATA MUORHO/8.0100,3.4450,1.1180,0.5588,0.3608,0.2734,0.2004,
     1 0.1704,0.1399,0.1250,0.1073,0.0958,0.0873,0.0807,0.0709,
     2 0.0637,0.0519,0.0448,0.0365,0.0319,0.0290,0.0270,0.0245,
     3 0.0231,0.0215/
C
C----USE LOG-LOG INTERPOLATION
      LOGINT(X,X1,X2,Y1,Y2) = EXP((ALOG(Y2)-ALOG(Y1))*
     1  (ALOG(X)-ALOG(X1))/(ALOG(X2)-ALOG(X1)) + ALOG(Y1))
C
C
      J=2
C-------use lowest two data points for energies below table
      IF(EKEV.LT.E(1)) GO TO 212
 200  IF(EKEV - E(J)) 212,211,210
 210  J = J + 1
      IF(J.LT.26) GOTO 200
C-------use highest two data points for energies above table
      GOTO 212
 211  MUCONC =  MUORHO(J)
      RETURN
 212  CONTINUE
      MUCONC = LOGINT(EKEV,E(J-1),E(J),MUORHO(J-1),MUORHO(J))
      RETURN
      END
```